MAINE AQUACULTURE REVIEW

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1.0 INTRODUCTION

1.1 BACKGROUND

Aquaculture began in Maine in the 1970s, with limited culture of mollusc and finfish. Atlantic salmon aquaculture grew and was well established in the 1980s. Over the past 12 years, the salmon farming industry has grown in Maine from 19 farms in 1990, producing 1.9m pounds (Parametrix 1990) to a production estimated at 12.54m pounds in 1992, with an estimated value of $37.5m. Maine's salmon industry in 1999 produced a estimated value of $64.1m (Goldburg et al. 2001). Currently, Atlantic salmon produce 96% of the revenue. In 2002, there were 1,203 acres of subtidal land leased for aquaculture: 44 lease sites for finfish (26 active, 750 acres); 80 lease sites for shellfish (445 acres) and one lease site for seaweed (7 acres, Fisk 2002). The latter is no longer in production (John Sowles, MDMR, personal communication).

Aquaculture monitoring in Maine initially occurred on a case-by-case basis with a focus on finfish. Site-specific monitoring plans were developed for each site by the Maine Department of Marine Resources (MDMR) and Department of Environmental Protection (MDEP) but responsibility for monitoring was that of the individual site operators. As monitoring reports were submitted, it soon became obvious that data collection quality and methodology were extremely variable. The result was that comparisons between sites and over time were not possible. To address the problem of inconsistent monitoring in 1991, a unified monitoring program was developed. The Maine Legislature created the Finfish Aquaculture Monitoring Program (FAMP), where the state became responsible for monitoring all the finfish sites. The program was funded by a 1-cent tax for each pound of salmon. The fee supported contracting with a single entity to conduct monitoring according to MDMR and MDEP protocols. Through this, the FAMP was able to provide consistency in review for all farms and instituted a quality assurance program.

The industry and husbandry practices have changed dramatically since the early 1990s and new issues have emerged. For example, wild Atlantic salmon were declared a federally listed endangered species in 2000 in rivers and streams from the lower Kennebec River north to the U.S.–Canada border. The rivers and streams include the Denny's, East Machias, Machias, Pleasant, Narraguagus, Ducktrap, and Sheepscot Rivers and Cove Brook. Concern has escalated over maintaining genetic integrity and health of wild salmon given possible contact with escaped farm-raised individuals, which could interbreed and transmit disease (Goldburg et al.2001). The increased density of farms and populations within farms increase the likelihood of disease such as the epidemic of infectious salmon anemia (ISA) in 2001 in Cobscook Bay (Bangor Daily News 2002). This latest epidemic forced the removal of all farmed salmon from Cobscook Bay in February 2002. The growth of the industry has resulted in increased numbers of facilities, creating conflicts with stakeholders that include the fishing community, coastal landowners, and recreational users. The increased number of facilities has also increased the number of interactions with seals (whose population has been steadily increasing) and other wildlife. A change in feeding technology, specifically the use of continuous feeding combined with a dry feed, has reduced the amount of excess feed and nutrient input.

1.2 SCOPE

Given the changing landscape and as has been done in the past, an interagency committee [U.S. Army Corps of Engineers (USCOE), U.S. Environmental Protection Agency (US EPA), U.S. Fish and Wildlife Service (USFWS), U.S. National Marine Fisheries Service (NMFS), Maine Department of Marine Resources (MDMR), Maine Department of Environmental Protection (MDEP), Maine Department of Inland Fisheries and Wildlife (MDIFW)] convened to review the existing monitoring program. The objective was "*to evaluate Maine's ability to assess severity and extent of effects of marine aquaculture on the natural environment, test the applicability of existing FAMP methods and to provide recommendations to the State on measures to improve environmental assessments."*

In subsequent meetings of the Interagency Technical Committee, it became clear the scope of work that included finfish, shellfish and algae culture was too large. Accordingly, the committee agreed to narrow the scope of this review to the Finfish Aquaculture Monitoring Program. Furthermore, it was agreed that Endangered Species Issues would not be dealt with in this review.

The scope of our investigation had three components: literature review, existing monitoring data evaluation, and proposed monitoring program.

The literature review focused on three main themes — impacts, monitoring, and emerging issues. Current literature on the potential environmental impacts posed by finfish aquaculture was reviewed, along with management strategies utilized in other regions. Monitoring protocols and regulations developed elsewhere were evaluated in terms of Maine's unique marine environment and regulatory framework.

The monitoring program evaluation was subdivided into water quality issues and biological issues, primarily benthos. The main objectives were to evaluate Maine's ability to assess severity and extent of effects of marine aquaculture on the natural environment and to test the applicability of existing Finfish Aquaculture Monitoring Program (FAMP) methods. For water quality, the following questions were addressed:

- Does FAMP in its current form meet the requirements established by regulatory framework?
- As such, has FAMP provided data with which MDMR can adequately assess effects from aquaculture on the marine environment?
- Can FAMP provide data necessitated by current and future permit requirements?
- If not, but deemed necessary by MDMR, how can FAMP be modified to adequately address the current requirements and emerging water quality concerns?

Benthic monitoring evaluation asked the following questions:

- Do measured parameters allow an assessment of regulatory compliance (i.e., "no unreasonable impact"(based on best professional judgement) to the balanced indigenous benthic community)?
- Do video observations confirm conclusions based on measured parameters (both water quality and benthic) in terms of degree of impairment?

The proposed monitoring program incorporates results from the existing data evaluation to include variables that are best able to meet existing and future regulatory requirements. Lessons learned from monitoring programs from other states and provinces were used to shape suggestions for FAMP.

2.0 LITERATURE REVIEW

2.1 REGULATORY REVIEW

Aquaculture is regulated by a number of federal and state regulations as listed in Table 2-1.

TABLE 2-1. FEDERAL AND STATE REGULATIONS GOVERNING MARINE AND ESTUARINE AQUACULTURE FACILITIES

Regulation	Jurisdiction	Description
Section 402, Federal Water Pollution Control Act (33 U.S.C. 402)	US EPA , delegation to MDEP	NPDES permits
Section 403, Federal Water Pollution Control Act (33 U.S.C. 403)	US EPA	Ocean Disposal Criteria
Section 103, Marine Protection Research and Sanctuaries Act (16 U.S.C. 1431).	USCOE	Disposal of dredged material in ocean waters
Section 404, Clean Water Act (33 U.S.C. 404)	USCOE	Fill in waters in the United States
Rivers and Harbors Act of 1899 (33 U.S.C. 403)	US ACOE	Governs structures in navigable waters
The Migratory Bird Treaty Act (16 U.S.C. 703 *et seq.*)	USFWS	Depredation permit required to kill protected species
Endangered Species Act 16 U.S.C. 1531 *et seq*.	USFWS/NMFS	Protects federally listed species and their habitats
Marine Mammal Protection Act (16 U.S.C. 1361 *et seq*.)	NMFS	Protects marine mammals
Magnuson Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 *et seq*)	NOAA	Governs Essential Fish Habitat
Federal Insecticide, Fungicide, and Rodenticide Act (7 U.S.C. 136 *et seq.*)	US EPA	Pesticide control
The Food, Drug, and Cosmetic Act (21 U.S.C. 301 *et seq*.)	Food and Drug Administration	Drug approval program
Water Classification Program 38 M.R.S.A., Article 4-A	MDEP	Establishes water quality standards for receiving waters
Subtidal Lands Lease for Aquaculture	MDMR	Includes both siting and monitoring

Discharges from "point sources" are regulated by the EPA under its National Pollution Discharge Elimination System permitting process. This process has been the cause of some debate, as virtually all facilities applied to US EPA Region I for NPDES permits but their applications were not processed. In January 2001, the Maine Department of Environmental Protection was delegated authority to issue NPDES permits. MDEP is in the process of developing an aquaculture general permit that could cover many of the State's existing and new aquaculture facilities to bring them into compliance with federal statutes. Adjudicatory hearings will be held by the Maine Board of Environmental Protection early in 2003.

In February 2001 US EPA granted a water quality permit to the Acadia Aquaculture net pen fish farm to operate in Blue Hill Bay (EPA 2001). Because some of the conditions were economically unfeasible, the applicant refused the permit and the lease voluntarily terminated. It was, however, the first and only federal net pen permit issued to an aquaculture facility in Maine (although Washington State has issued permits for years and Maine DEP issued permits prior to 1989) and provided permit writers with a constructive exercise to address the difficult issues permitting a non-pipe discharge such as net pen aquaculture.

EPA's permit included numerous conditions and standards that would have:

- limited the total annual amount of fish feed that may be used at the site unless studies are completed to show that higher levels of nutrient addition can safely be allowed;
- required bottom monitoring with enforceable limits on conditions under and around the pens;
- required frequent water column monitoring with specific dissolved oxygen limits at the pen site;
- limited the use of fish medications;
- incorporated U.S. Fisheries and Wildlife Service recommendations for wild Atlantic salmon protection.

Since 1992, US EPA has been developing national effluent limitation guidelines and new source performance standards for concentrated aquatic animal production point source categories Draft guidelines were recently proposed (FR, 9/12/2002, pages 57871-57928). The focus of the proposed rules emphasized use of Best Management Practices, primarily feed monitoring systems. The review also acknowledge the difficulties in permitting net pen aquaculture as opposed to conventional pipe discharges, especially regarding the site-specific and regional nature. One option, in fact the option preferred by the Joint Subcommittee on Aquaculture (JSA) is the "no rule" option in recognition of the strong regional differences and scientific uncertainty associated with net pen aquaculture discharges.

Section 404 of the Clean Water Act governs fill in waters of the United States, regulated by The US Army Corps of Engineers. The Corps is also responsible for regulating the placement of structures in navigable waters through the Section 10 permitting process of The Rivers and Harbors Act. Other statutes include the Migratory Bird Treaty, authorizing U.S. Fish and Wildlife Service (USFWS) to regulate the killing of protected birds. USFWS is also responsible for the protection of non-aquatic endangered species listed under the Endangered Species Act. USFWS shares this responsibility with National Marine Fisheries (NMFS), who has responsibility for aquatic species. NMFS also is responsible for the protection of marine mammals under the Marine Mammal Protection Act. Drugs administered to aquaculture species are regulated by the Food and Drug Administration. Pesticides are regulated by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act.

The Magnuson-Stevens Fishery Conservation and Management ("Magnuson") Act established fishery management plans for conservation and management of fishery resources and mandated that habitat identified as "essential fish habitat" ("EFH") for managed fish species for spawning, breeding, feeding, or growth be protected.

At the state level, aquaculture facilities require a lease from the Department of Marine Resources, which is responsible for processing the lease application and evaluating potential environmental effects. The lease application must characterize potential environmental impacts of the project, meeting the following standards:

1. Will not unreasonably interfere with the ingress and egress of riparian owners;
2. Will not unreasonably interfere with navigation;
3. Will not unreasonably interfere with fishing or other uses of the area taking into consideration the number and density of aquaculture leases in an area.
4. Will not unreasonably interfere with other aquaculture uses;
5. Will not unreasonably interfere with the ability of the lease site and surrounding areas to support existing ecologically significant flora and fauna;
6. The applicant has demonstrated that there is an available source of organisms to be cultured for the lease site; and
7. The lease does not unreasonably interfere with public use or enjoyment within 1,000 feet of municipally owned, state owned or federally owned beaches and parks or municipally owned, state owned or federally owned docking facilities.

Comments from state, federal and municipal agencies including Inland Fish and Wildlife, Bureau of Parks, Harbormasters, Department of Environmental Protection and others are submitted for consideration by MDMR.

Maine Department of Environmental Protection is responsible for ascertaining that any discharge will not violate state water quality standards. The FAMP was established in 1991 through collaboration with cooperating state and federal agencies (US EPA, USCOE, NMFS, USFWS, and MDEP. The Finfish Aquaculture Monitoring Program (FAMP) was specifically designed to provide information that could enable the MDEP and MDMR to determine whether a finfish facility meets the requirements of Maine's Water Quality Standards (38 M.R.S.A., Article 4-A, Water Classification Program, Waste Discharge Law 38 M.R.S.A. §413 (2-F)) and the Salmon Aquaculture Monitoring Law 12 M.R.S.A. §6078 (4). Under MDEP Title 38 (Water Classification Program), the standards for Class SB waters state: “Discharges to Class SB waters shall not cause adverse impact to estuarine and marine life in that the receiving waters shall be of sufficient quality to support all estuarine and marine species indigenous to the receiving water without detrimental changes in the resident biological community.” FAMP monitoring has focused on “worst-case” time of year and was intended as a screening tool. If conditions under and around a farm warranted, additional sampling could be done to support an enforcement case. The FAMP also provides data for reviewing current environmental requirements and possible future modifications.

The FAMP has the following components:

- monthly confidential production reports from lease-holders
- Dissolved oxygen monitoring during the warmest part of the year and when fish biomass is highest, generally late August and September.
- Benthic video monitoring in spring and fall
- Biennial fall benthic infauna sampling

Monitoring is conducted by an independent contractor funded by the industry through a fee based on production.

2.2 LITERATURE REVIEW

Environmental impacts of net pen aquaculture have been extensively researched and documented.

2.2.1 Finfish Culture

Finfish net pen culture has significant differences from other forms of aquaculture such as shellfish or marine algae for several reasons. First, finfish are more intensively cultured in the sense that there is more biomass per unit area. Second, they require the addition of feed, which not only intensifies the effects of nutrient loading but also introduces potential contaminants. Nash (2001) reviewed impacts from salmon net-pen culture in the Pacific Northwest, categorizing them in terms of the level of risk (Table 2-2).

TABLE 2-2. SOURCES OF ENVIRONMENTAL RISK FROM SALMON NET CULTURE AND LEVEL OF PRESUMED RISK (SOURCE: NASH 2001)

Risk Level	Source
High	Deposition from feces and uneaten feed, leading to anoxic sediments and changes in benthic community structure
	Sediment accumulation of heavy metals and organics from anti-fouling compounds and fish feed
	Impacts from pharmaceuticals and pesticides on other species
Low	Effects of low oxygen, hydrogen sulfide, and ammonia on other species
	Toxic algae blooms resulting from nutrient enrichment
	Changes in the epifaunal community
	Proliferation of human, fish and shellfish pathogens in the aquatic environment; increased disease in wild fish
	Market displacement of wild salmon by farmed varieties
Little or none	Escape of non-native salmon, with resultant hybridization or colonization of native habitat
	Competition with or predation on native species for forage
	Introduction of exotic pathogens or contribution to the development of antibiotic-resistant bacteria
	Impacts on human health and safety from salmon consumption or working in/around facilities

Based on this list, benthic deposition of food and feces, with subsequent effects from increased organics and potential contaminants and toxics, have the highest likelihood of adverse effects on the environment. Impacts on water quality are considered to have less of an effect on the environment and primarily result from decreased dissolved oxygen and increased nitrogen concentrations. Fish farming contributes nutrients to the water column and underlying benthos in the form of fish waste and uneaten fish food. Older literature reports waste food on the order of 20-30% (Beveridge 1996) when the industry relied on moist food. More recent work in Maine suggests that, with the use of dry food, loss to the bottom averages less than 5% (Findlay and Watling 1995). Their work estimated that total proportion of labile organic carbon from feed that settles under net pens, combining both uneaten feed and salmon feces, is approximately 8.8%. Subsequent effects on the benthos and water column are summarized in Table 2-3. Feeding method and other husbandry practices can affect the amount of loss. The use of automatic feeding can increase the food loss; however, coupled with video monitoring, food loss can be minimized. Deposition of feed and feces beneath floating fish cages also vary, with local topographic and hydrographic conditions, in particular current and depth, which strongly affect the distribution and amount of material that reaches the sea floor (Weston 1986). These physical conditions along with standing stock on site impact on localized dissolved oxygen levels. It is estimated that 70% of nitrogen fed to fish is released as soluble ammonium (Gowen 1988).

TABLE 2-3. CHANGES TO THE BENTHOS AND WATER COLUMN ASSOCIATED WITH ORGANIC ENRICHMENT WITH ORGANIC WASTE FROM INTENSIVE FLOATING CAGE CULTURE (SOURCE: GOWEN ET AL.1990)

Effect	Type
Sediment Chemistry	Reduction in redox potential
	Increase in sedimentary carbon and nitrogen
	Methane, hydrogen sulfide production
	Enhanced remineralization of organic nitrogen
Biological	Growth of sulfur bacteria (e.g., *Beggiatoa*)
	Reduction in macrofauna biomass, abundance, and species composition
	Increase in biomass of opportunistic species (e.g., *Capitella capitata*)
Water Column	Eutrophication and hypernutrification
	Reduction in dissolved oxygen (respiration and BOD)

One of the most important aspects in understanding, evaluating, and in turn monitoring the impacts of aquaculture is the question of scale. Aquaculture impacts may occur on a variety of spatial and temporal scales. Silvert (1992) categorized these as internal, local, and regional. Internal impacts are most closely associated with dissolved oxygen reduction due to respiration. This impact is observed within and in the immediate vicinity of the pens and over a relatively short time frame – minutes to hours. Local impacts most directly affect the benthos and the seafloor in the vicinity of the pens. Although the spatial scale of these impacts is similar to that of internal impacts, the temporal response of the benthos to organic loading is generally considered to occur over months to years. The effect of aquaculture on a regional level is often associated with conveyance of disease and impact on wild species (competition or genetically). These issues are not addressed directly by FAMP or this report, but one impact that is discussed relates to the impact of dissolved nutrients (including BOD) on the ecosystems of the bays and estuaries where the aquaculture facilities are located.

Many of the benthic impacts have been quantified from monitoring activities conducted in Maine and elsewhere in the world. However, these impacts represent discrete times, locations and operating conditions and cannot represent the full spectrum of impacts around aquaculture facilities. In an earlier outside review of the FAMP, Parametrix (1990), recommended that the State of Maine utilize modeling to answer siting questions and predictions of “dilution and dispersion” of facility byproducts. Researchers have turned to modeling in an effort to simulate a range of conditions, with an added benefit of predicting impacts for future or expanded facilities. Silvert (1992, 1994) and Gowen (1994) used particle settling principals to predict carbon loading, using the factors of the settling rate of the feed, current speed, and depth. Once deposited, the ambient benthic and epibenthic community determines the rate of carbon processing. Associated benthic effects are the result of a more complex process and are not as easily modeled. Here in Maine, Sowles et al. (1994) and Silvert and Sowles (1996) examined 23 salmon farms and found good agreement with carbon accumulation model results and an index of predicted benthic conditions. This enabled them to develop a predictive model that described levels of benthic impact based on quantity of fish on site, depth, and current velocities. These results can begin to address the more complex question of "carrying capacity" or holding capacity i.e. the number of fish that can be supported in a given water body while maintaining the environmental quality, both in the water column and benthos. Models developed to address these questions must integrate factors such as tidal flushing, runoff, and meteorological conditions. Preliminary results (Silvert 1994) are encouraging and the principals of fuzzy logic offer promise (Silvert 1997).

In addition to the organic loading associated with feed, constituents of feed may also be deposited in sediments from uneaten feed or feces. If present in sufficient quantities, there exists a potential ecological risk to benthic infauna. Salmon feed contains zinc as a mineral supplement. A study of 27 salmon farms in British Columbia (Brooks 2000a) found that exceedances of the aquatic effects threshold in 10% of the samples, with significant correlation between Total Volatile Solids (TVS) and sediment sulfides. Since toxicity is inversely related to AVS concentration, however, Brooks also concluded that "no effects should be anticipated from the observed concentrations of sediment zinc under salmon farms." His work also demonstrated the highly localized and rapidly returned to background levels once the farms were fallow. Concentrations of copper in sediments surrounding net pens have been shown to be elevated from use of antifouling paints and solutions. Brooks (2000b) found that sediment copper concentrations did not differ significantly among farms using Flexgard™-treated nets, farms with untreated nets, and reference sites. However, copper exceeded NOAA ER-M and Washington Sediment Quality criteria in 11% of sediment samples around 14 British Columbia farms Brooks found clear evidence that elevated copper was a result of net washing, which dislodges paint chips, rather than leaching or erosion. Thus, husbandry practices can help mitigate these effects.

Organic compounds also are present in salmon feed, with evidence of bioaccumulation in salmon flesh. Easton et al. (2002) found commercial feed contained PCBs, organochlorine pesticides, brominated diphenyl ethers, PAHs and dioxins. Studies in New Brunswick (Burridge et al, 1999) where tides are similar to Maine tides but with an industry twice as large and has operated for a longer period of time also show elevated levels of metals and organic compounds in the vicinity of pens but the levels were not sufficient to suggest toxicity. The presence of contaminants in sediments around salmon pens and the potential for ecological risk has been initiated in 2001 here in Maine (John Sowles, MDMR, personal communication).

Net-pens and associated moorings can cause disturbance to the underlying substrate and associated benthic organisms. Net cleaning can also cause bottom disturbance and additionally result in deposition of formerly attached epiphytic organisms such as algae and blue mussels (Silvert and Sowles 1996). Potential benefits from fouling organisms on nets, removing particulates from the water column, have not been quantified.

Aquaculture activities can have both direct and indirect effects on water quality. The most obvious direct impact is a direct and immediate decrease in dissolved oxygen concentration due to fish respiration. The magnitude of the decrease is related to a variety of factors including biomass, pen configuration, current velocity, and topography. In Puget Sound, dissolved oxygen reductions of up to 2 mg/L in water passing through aquaculture pens have been observed although in most cases the decrease is ≤0.5 mg/L (Nash 2001). The sensitivity of salmonids to lower oxygen levels (6 mg/L considered a minimum for optimal health, Nash 2001) provides a direct incentive for minimizing this impact either by site location or reductions in stocking. Indirect impacts are related to inputs and distribution of nutrients and organic matter (primarily dissolved, but also small suspended particulates) into the surrounding waters. Nutrients, specifically nitrogen, have a secondary effect associated with the potential increase in primary production and phytoplankton with a worst case scenario resulting in harmful algal blooms The dissolved and suspended organic matter ultimately contributes to the BOD of the system. It has been suggested by many scientists that these indirect effects on water quality should be evaluated using a modeling approach to understand the assimilative capacity of the embayment where current or proposed aquaculture sites reside.

Food web effects can extend beyond water quality and benthic effects. The aggregation of fish can attract and entangle predators that include seals, birds and other species. Facility activities can increase noise and light, potentially disturbing nesting marine birds. The effects of aquaculture on shorebirds in Maine does not appear to be a large concern, especially since there is a 0.25-mile limit around identified nesting areas. However, impacts on aquaculture have not been quantified nor has the sufficiency of the 0.25-mile limit been tested (Steve Timpano, MDIFW, personal communication). Predation by marine mammals has also been an issue. Anecdotal evidence indicates there is a large variation in seal predation and associated damages at finfish facilities in Maine. An ongoing investigation is looking at these interactions/predation events and determining factors that influence predation frequency and levels at finfish farms including: proximity to seal haul-outs, husbandry practices, and use of predator-deterrents. Anecdotal evidence from Maine salmon farmers points to husbandry practices as a major contributing factor to predation occurrences, i.e., cleaning of mortalities on a regular basis. Others have indicated that “acoustic harassment devices” have limited effectiveness and that seals habituate to them. It is in the Industry’s best interest to minimize these interactions, and it is currently making use of a variety of tools to keep reduce them (Marcy Nelson, University of Maine, personal communication.). Studies at salmon farms in New Zealand have found a correlation between predation and proximity to Australian fur seal haul-outs (Pemberton and Shaughnessey 1993).Pemberton and Shaughnessy (1993) found that the frequency of predation on fish-farms in Tasmania increased with decreasing proximities from Australian fur seal (*Arctocephalus pusillus doriferus*) haul-out sites.

3.0 EXISTING MONITORING DATA REVIEW

3.1 WATER QUALITY

3.1.1 FAMP Sampling Protocols

The main focus of FAMP as it relates to water quality is on the measurement of dissolved oxygen. Additional *in situ* data are collected for pressure (depth), temperature, salinity, and pH. Percent saturation is also calculated based on dissolved oxygen concentration and ambient temperature and salinity. Details on the use and calibration of the instruments are provided in Heinig 2000a. This data review focuses on the dissolved oxygen concentration and percent saturation data.

The original monitoring protocol developed in 1991 called for semimonthly sampling of dissolved oxygen by the operators at each lease site July, August and September. Additional oxygen profile measurements were made annually in August at three stations upstream, in the vicinity and downstream of the sites in August. As might be expected, the data from the initial efforts in 1992 and 1993 was 'sporadic and of questionable quality' (Heinig 2000a). To reduce data variability and increase reliability, MDMR and MDEP restructured the program in 1994 and hired a single contractor to make the measurements at all lease sites. From 1994 to 2002 (excluding 1997 and 2000), annual measurements of these in situ parameters were made in September or October at stations 100 m upstream, 5 m downstream, and 100 m downstream of the pens. As the descriptions suggest, the stations are selected each year based on pen configuration and prevailing currents. Although this is a valid and reasonable sampling approach, it makes interannual and between site comparisons difficult to interpret. It should also be noted that sampling location and distances from sites/pens will be a critical factor in the development of both general and site-specific permit monitoring/compliance requirements.

3.1.2 Data Compilation

FAMP data are currently stored as individual Seabird output files or Lotus/Excel spreadsheets. Due to the major data management effort that loading all of the data into a database would entail, only a subset of the FAMP water quality data were used in this analysis. From the 35 sites listed in Table 3-1, eight sites were selected based on location to provide adequate geographical distribution (Table 3-2). A subset of four sites was selected for examination of interannual trends based on data availability. All temperature, salinity and dissolved oxygen profile data collected at these sites and years have been compiled in an MS Access database. The 1995 to 1999 data were converted directly from Seabird output files to MS Excel and imported, while 2001 data were available in MS Excel format. As the 2001 data were readily available all sites visited in that year have been added to the database and included in this evaluation. The additional 14 sites are also listed in Table 3-2 (Note that some of these sites do not appear in Table 3-1 as they are either new or the names have changed). Data from the two primary control sites in Cobscook and Machias Bays were also loaded and included in the evaluation.

TABLE 3-1. SALMON FARMS, OWNERS, LOCATIONS, AND YEARS WHEN BENTHIC INFAUNA DATA WERE COLLECTED

Site Name	Owner	Location	Town	Depth*	Baseline (Year)	First year of benthics	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ASMI CI	Atlantic Salmon of Me	Cross Island		50	NO	1992		FB		FB		FB		FB	S	FB,S
ASMI DI	Atlantic Salmon of Me	Dyer Is	Harrington	48	1994	1997							FB		FB,S	S
ASMI FI	Atlantic Salmon of Me	Flint Is.	Harrington	39-47	1993	1995						FB	FB		FB	S
ASMI II	Atlantic Salmon of Me	Starboard Is	Machiasp.	**40-44**	1991-LIMITED	1994				FB		FB		FB	FB	FB,S
ASMI LI	Atlantic Salmon of Me	Libby Is.	Machiasp.	54	1992	1994					FB					FB,S
ASMI ST	Atlantic Salmon of Me	Stone Is.	Machiasp.	45-50	1995	2000									FB,S	FB,S
BPFI BE	Birch Point Fisheries	Birch Pt	Eastport	30-39	NO	1993					FB				FB	
CONA BC	Connors Aquaculture	Broad Cove	Eastport	50	NO	1992		FB		FB		FB		FB, 6200, 6000	S	FB,6100, 6200
CONA CP1	Connors Aquaculture	Comstock Pt	Lubec	50	NO	1992 - as CONA CP				FB		FB AS CP		FB	S	FB (IN)
CONA CP2	Connors Aquaculture	Comstock Pt	Lubec	39-48	1989-LIMITED	1992 - as CONA CP				FB		FB AS CP			S	
CONA DC	Connors Aquaculture	Deep Cove	Eastport	41	NO	1992				FB		FB		FB-IN, OUT		FB (IN, OUT)
CONA SB	Connors Aquaculture	South Bay, Sw Gove pt	Lubec	55	NO	1995					FB		FB-1,2,3		FB-IN	FB,I,O, M
DESC GN1	D E Salmon Co.	Gove Pt.		25	NO	1992 as NESC GN		FB		FB		FB AS GN			FB	
DESC GN2	D E Salmon Co.	Gove Pt.	Lubec	72	1994	1992 as NESC GN						FB AS GN			FB	
DESC LU	D E Salmon Co.	Johnson Bay	Lubec	**41-45**	1991-LIMITED	1995 as STEV LU						FB		FB	S	FB,S
IACO HS	Island Aquaculture	Harbor Is.	Swans Is.	55	1990 and 1993	1991 as MPLT TC then 1994 as IACO HS						FB			FB	
IACO TC	Island Aquaculture	Toothaker Cove	Swans Is.	47-50	1988-LIMITED	1992 as MPLT TC		FB		FB		FB			FB	S
IAFI CL	Int'l Aqua Foods	Harris Cove	Eastport	48	NO	1993 as HANK CL			FB		FB					FB,S
IAFI HP	Int'l Aqua Foods	Harris Cove	Eastport	21-40	1994	1999 as MAFI HP									FB	FB

TABLE 3-1. SALMON FARMS, OWNERS, LOCATIONS, AND YEARS WHEN BENTHIC INFAUNA DATA WERE COLLECTED (CONT'D)

Site Name	Owner	Location	Town	Depth*	Baseline (Year)	First year of benthics	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
IAFI JK	Int'l Aqua Foods	Kendall Head, Johnsons Cove	Eastport	30	NO	1992 & 1994 as HARS JK then 1996 as HARS JK1	FB		FB	FB, JK2	FB				FB,JK1,2	
IAFI PC	Int'l Aqua Foods	Prince Cove	Eastport	36	NO	1993 as ISSI PC then 1995 as MAFI PC		FB		FB			FB	S	S	FB,S
LREN TE	L R Enterprise	Treats Is	Eastport	30	NO	1993 as ECFF TE then COOK TE		FB		FB			FB	S	S	FB,S
MCNB SCN	Maine Coast Nordic	Sand Cove N	Beals	45	1995	2001										
MCNC CH	Maine Coast Nordic	Cutler Harbor	Cutler	25	NO	1993		FB		FB		FB		FB	FB	FB,S
MCNC CN	Maine Coast Nordic	Little River	Cutler	**23-29**	1992	1993	Owner operated, low impacts despite shallow depth.						FB	FB	FB	S
MCNI CW	Maine Coast Nordic	Cutler Penn,W	Cutler	30	1991 (Intertide Corp.) - Bent. Inf. Not Analyzed	1995	Site abandoned			FB						
MCNI SI	Maine Coast Nordic	Spectacle Is	Beals	33	1991 (Intertide Corp.) - Bent. Inf. Not Analyzed	1993 as RLLT SI				FB		FB		FB,S	FB,S	FB,S
SFML JB3	Stolt Farm	Johnson Bay	Lubec	27-40	1993	1992 as SFML JB		FB	FB	FB		**FB**		FB,S	FB,S	S
SFML RN	Stolt Farm	Rogers is	Lubec	35	NO	1993 as RISC RN				FB		FB		FB	FB	S
TIFI CC	Treats Island Fisheries	Comstock Cove	Lubec	30	NO	1992 as NBFI CC		FB	FB					FB	FB	
TIFI JC	Treats Island Fisheries		JC		NO	1992 as NBFI JC		FB	FB		FB					
TIFI TW1	Treats Island Fisheries	Treats Is	Eastport	35	NO	1993 combined with TIFI TW2 as TIFI TW				FB			FB (tw)	S	S	FB
TIFI TW2	Treats Island Fisheries	Treats Is	Eastport	35	NO	1993 combined with TIFI TW1 as TIFI TW										FB
TISF HT	Treats Island Fisheries	Hardwood Is/Trumpet	Blue Hill	108-180	1992	1994	A lot of impact downcurrent to south				FB			S	S	S

*Sites that have been transferred to new leaseholders in the past will likely have different acronyms. The last two/three letters (depicting site location) of a given acronym will remain consistent regardless of leaseholder.
*The majority of baselines from 1992-present were performed by MER Assessment Corp.
Depth is very approximate, gleaned from site maps. FB= FALL BENTHOS. S=SPRING VIDEO SURVEY

TABLE 3-2. LEASE SITES AND YEARS SELECTED FOR WATER QUALITY EVALUATION

Site	Location	Town	Years
ASMI CI	Cross Island	Machiasport	95, 96, 98, 99, 01
BPFI BE	Birch Point	Eastport	95, 96, 98, 99, 01
CONA BC	Broad Cove	Eastport	99, 01
CONA SB	South Bay/Gove Pt.	Lubec	95, 96, 98, 99, 01
IAFI PC	Prince Cove	Eastport	99, 01
MCNC CH	Cutler Harbor	Cutler	99, 01
SFML JB3	Johnson Bay	Lubec	99, 01
TISF HT	Hardwood Is	Blue Hill	95, 96, 98, 99, 01
Control 1	Birch Pt./Gove Pt.	Eastport	95, 96, 98, 99
Control 2	Chance Is/Point Ruth	Machiasport	96, 98, 99, 01
ASMI CC	Cooper’s Ledge	Lubec	01
CONA CP	Comstock Point	Lubec	01
CONA DC	Deep Cove	Eastport	01
IACO BL	Black Island		01
IACO HS	Harbor Scragg	Swans Is.	01
IACO TC	Toothaker Cove	Swans Is.	01
IAFI HP	Harris Point	Eastport	01
IAFI JK	Johnson Cove/Kendall Head	Eastport	01
MCNB SI	Sand Island		01
MCNB SCN	Sand Cove North	Beals	01
MCNC CN	Cutler North	Cutler	01
MESI SH	Shackford Head		01
SFML RN	Roger's North	Lubec	01
SFML RS	Roger's South	Lubec	01

Objectives and Analytical Approach

As stated in the introduction, the objective of this project is to evaluate MDMR’s ability to assess the severity and extent of effects of marine aquaculture on the natural environment based on FAMP data and to test the applicability of existing FAMP methods. Numerous data analyses to date have indicated that dissolved oxygen levels are normally well above state standards and during those instances when percent saturation levels are below the 85% standard, they are only slightly lower than the standard and usually only at a limited set of depths that are sampled (Heinig 2000a and references therein). Additionally, the dissolved oxygen concentrations are well above levels that might cause adverse biological effects. One of the goals of the evaluation is to determine if these results are representative of conditions or, in fact, a function of the sampling methodology used by FAMP. This analysis focuses on the frequency and timing of measurements, the parameters measured and the spatial extent of measurements.

The FAMP data are used to address two fundamental questions:

1. Does FAMP in its current form meet the requirements established by regulatory framework?

2. As such, has FAMP provided data with which MDMR and MDEP can adequately assess effects from aquaculture on the marine environment?

3.1.3 Results

FAMP data have been compared against Maine water quality standards in each of the annual monitoring reports and have been summarized in the Eight-Year Overview (Heinig 2000a). For class SB coastal waters, DO percent saturation must be greater than 85%. For the years evaluated in Heinig 2000a (1992-1999), less than 5% of the profiles had readings less than 85% (47 out of 1,085). Of these, only two of the profiles that had readings less than 85% were recorded at stations 100 m from the pens. The other 45 profiles were recorded within 5 m of the pens. Please note that many of these profiles are replicates from the same sampling locations. It should also be noted that the majority of these profiles had only intermittent readings below 85% and that most of those ranged from 80 to 85%. Clearly the FAMP data indicate that DO levels are relatively high and that the pens are almost always within water quality standards for percent saturation when monitored.

Although we did not review all of the data from 1992 to 1999, the four sites chosen for evaluation over the pre-2001 time period did include a majority of the 85% exceedances (25 of the 47 noted in Heinig 2000a). These 25 profiles were from a total of 13 sampling stations as almost all were duplicate profiles and all but one of the stations was 5 m downstream of the pens (Table 3-3). All told there were 304 individual sensor readings below 85% out of a total of over 12,500 (2.4%). Almost all of the low readings were between 75-85% and had DO concentrations of ≥7 mgL^{-1}. The only station that had lower DO than 75% was at ASMI-CI in 1996 and it was located 5 m downstream where percent saturation values reached a minimum of 65%. Even at this low level, however, DO concentrations did not go below 6 mgL^{-1}. In 2001, DO values of less than 85% were only observed at 3 sampling stations (6 replicate profiles). Although the total number of sensor readings increased, they still accounted for only 2.3% of all readings (504 of ~21,600).

TABLE 3-3. SAMPLING STATIONS WITH DISSOLVED OXYGEN PERCENT SATURATIONS LEVELS <85%

Location	Year	Station	Minimum DO (% saturation)	Minimum DO (mgL^{-1})	Count of Readings <85%	Total Number of Readings
ASMI-CI	1995	5d1	84.43	7.50	4	151
ASMI-CI	1995	5d3	79.74	7.07	44	57
ASMI-CI	1995	5d4	79.44	7.05	46	139
ASMI-CI	1995	5d5	79.43	7.02	19	62
ASMI-CI	1995	5d6	79.97	7.07	43	121
ASMI-CI	1996	5d2	65.47	6.02	20	244
ASMI-CI	1998	5d2	84.28	7.72	9	102
ASMI-CI	1998	100d1	83.44	7.63	21	90
ASMI-CI	1999	5d1	78.41	6.94	31	146
CONA-SB	1995	5d1	84.94	7.48	1	176
CONA-SB	1999	5d1	84.36	7.22	4	162
CONA-SB	1999	5d2	82.15	7.04	50	226
IACO-BL	2001	5d1	78.24	6.79	216	388
IACO-BL	2001	5d2	81.56	7.06	206	512
IAFI-JK3	2001	5d2	84.28	7.37	92	124
TISF-HT	1995	5d1	82.62	7.17	12	238

In the FAMP annual water quality reports, the profile minima have been presented by sampling location for each site. This is relevant in the context of comparing monitoring data against the Maine state standard of 85% dissolved oxygen saturation for class SB waters. This type of compliance monitoring has been the focus of the FAMP water quality program – essentially does the site meet the established state standard? Comparisons across and between sites based on these profile minima, however, are meaningless unless there is an assumption that these individual minima are representative of a particular section of the water column for every profile. A more appropriate metric for comparison would be depth interval, i.e., the surface or bottom waters based on pycnocline depth, pen depth, or a specific depth bin. A preliminary evaluation of the in situ profiles suggested that a surface water layer from 0 to 10 meters was the most appropriate metric from comparisons within and across sites. Most sites exhibited only minor stratification as the water column was relatively well mixed. The most notable exception was at TISF-HT, where a pycnocline was often observed at ~10 m. Additionally, trends in DO data indicated that depressions in concentrations usually occurred in the vicinity of the pens, which are located in the upper 10 m of the water column. Figure 3-1 shows the temperature and DO profiles at the 5 m downstream sampling stations at TISF-HT and IACO-BL and illustrates why this depth interval was chosen. Comparisons of mean surface water (0-10 m) within sites also provides a mechanism to calculate apparent oxygen demand through the pens or at least an estimate of the relative impact of fish respiration locally.

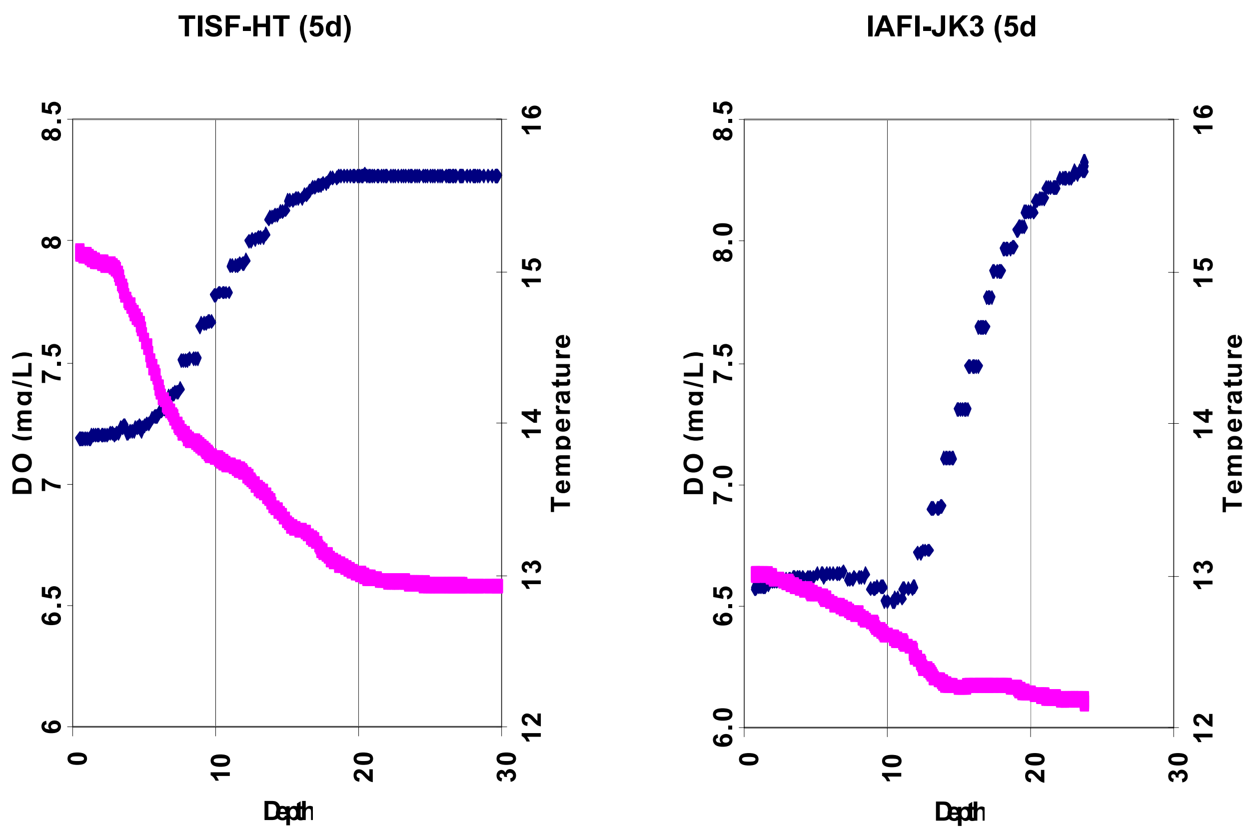


FIGURE 3-1. IN SITU PROFILES OF TEMPERATURE (°C) AND DISSOLVED OXYGEN (MGL-1)

FAMP is focused on site-specific compliance monitoring, but comparison of data across sites both within and between water bodies provides additional insight for delineating potential problem areas. To make the comparisons of surface water DO manageable, the data from replicate profiles were averaged and, using best professional judgment, sampling stations were averaged as appropriate. For instance, at many of the sites there are multiple 100 m upstream stations, but essentially these are replicates of the same upstream water mass and were grouped together for this analysis. This was also done for many 5 and 100 m downstream stations. In some cases the pen configuration and sampling schema were not conducive to this type of pooling and the data continued to be grouped based on individual sampling station. In 2001, this was the case for both ASMI-CI and IAFI-JK3 (Figure 3-2). At all of the other sites, data were averaged over replicate profiles and pseudo-replicate stations. For the four sites evaluated from 1995 to 2001, only TISF-HT allowed for this type of averaging. At the other three sites, the complexity of the site configuration and the year-to-year changes in that configuration and the sampling schema resulted in multiple stations for each year and an inconsistent number of stations over the five years of monitoring.

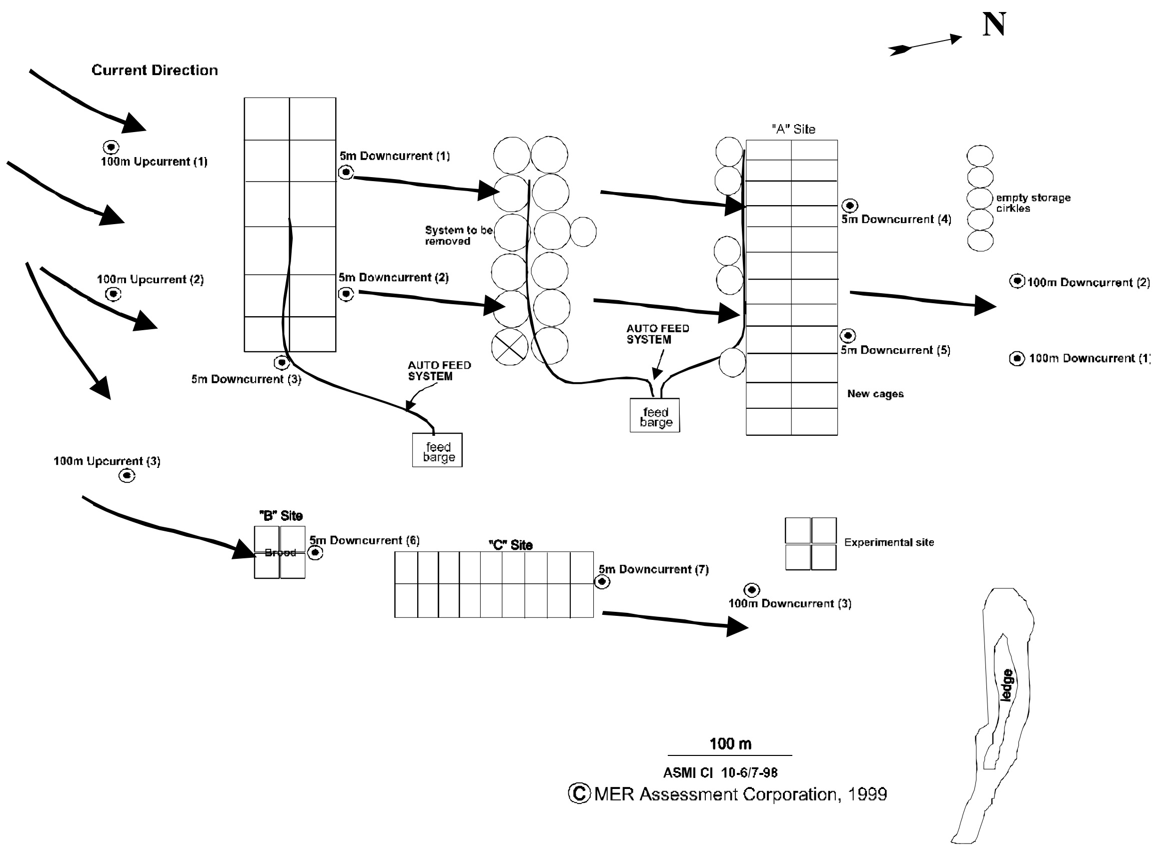
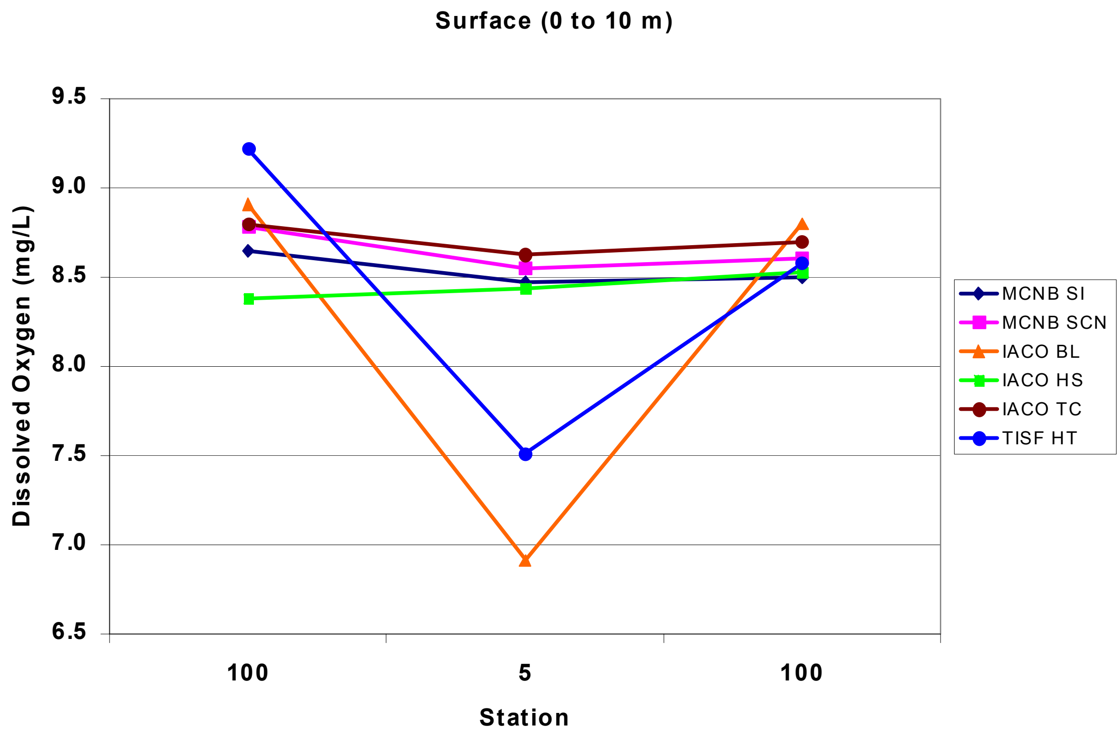


FIGURE 3-2. PEN CONFIGURATION AND SAMPLING STATIONS AT ASMI-CI IN 2001

All of the mean surface DO percent saturation and concentration results for 2001 were plotted by geographic area. The only sites that exhibited a substantial difference between 100 upstream and 5 m downstream sampling stations were TISF-HT and IACO-BL (Figure 3-3). The range in surface water DO concentrations in Cobscook and Machias Bays was generally between 8 and 8.5 mgL^{-1} and showed only minor variations at each site similar to the other four sites depicted in Figure 3-2. The low DO level at 5 m downstream for IACO-BL was evident in the cursory review of DO percent saturation readings below 85%. The nearly 2 mgL^{-1} oxygen deficit between upstream and 5 m downstream stations at both IACO-BL and TISF-HT, however, was not. One common flaw in interpreting FAMP is the focus on comparisons against the 85% limit that is currently the oxygen standard for most waters in which net pens are located.

It would be useful to take this example a step further and develop estimations of apparent oxygen demand (AOD) based on the water quality measurements and physical oceanographic data. One issue that has been raised concerns the ability of FAMP to capture minimum DO levels. Although the scheduling of the surveys in September/October increases the likelihood of capturing the DO minima, the use of AOD as an indicator provides additional information as to whether a specific lease site may have a detrimental impact on DO levels. Even though DO percent saturation at TISF-HT was above the 85% standard, the fact that there was an oxygen deficit of almost 2 mgL^{-1} is significant. The reduction suggests the potential that the standard could be exceeded if ambient concentrations were already near 85%. It should be noted that all but one of these instances where DO percent saturation was <85% (see Table 3-3) occurred within 5 m of the pens.



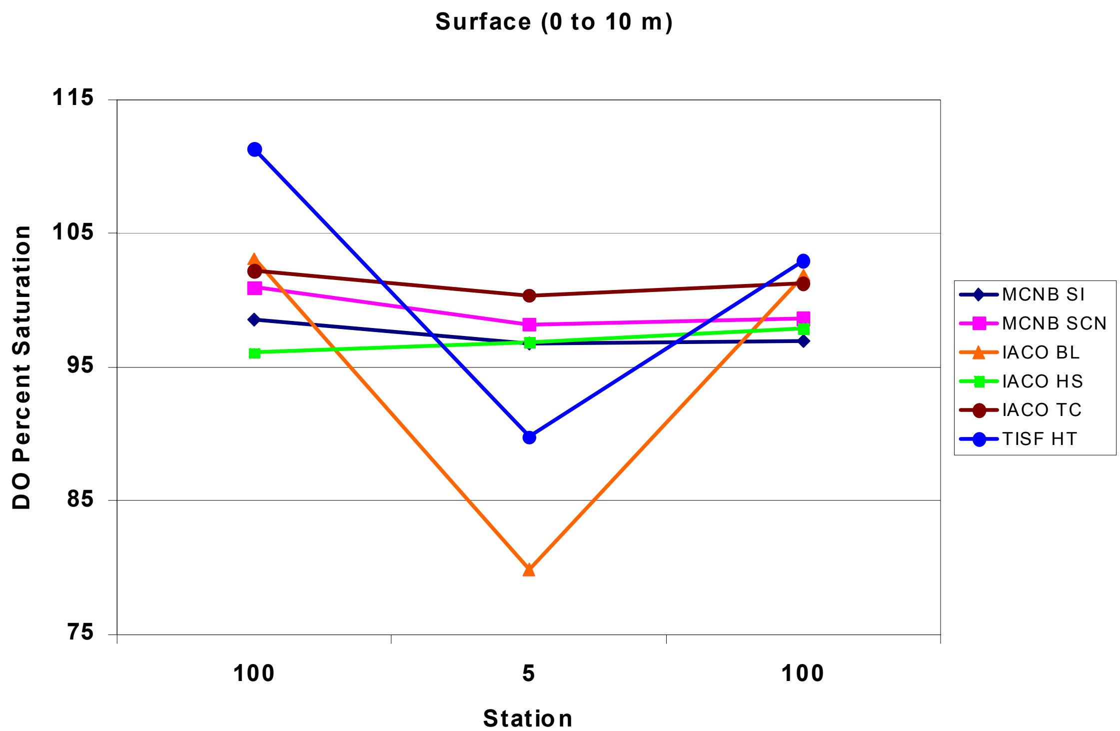


FIGURE 3-3. SURFACE (0-10 M) DISSOLVED OXYGEN CONCENTRATION (MGL^{-1}) AND PERCENT SATURATION AT LEASE SITES IN BLUE HILL BAY

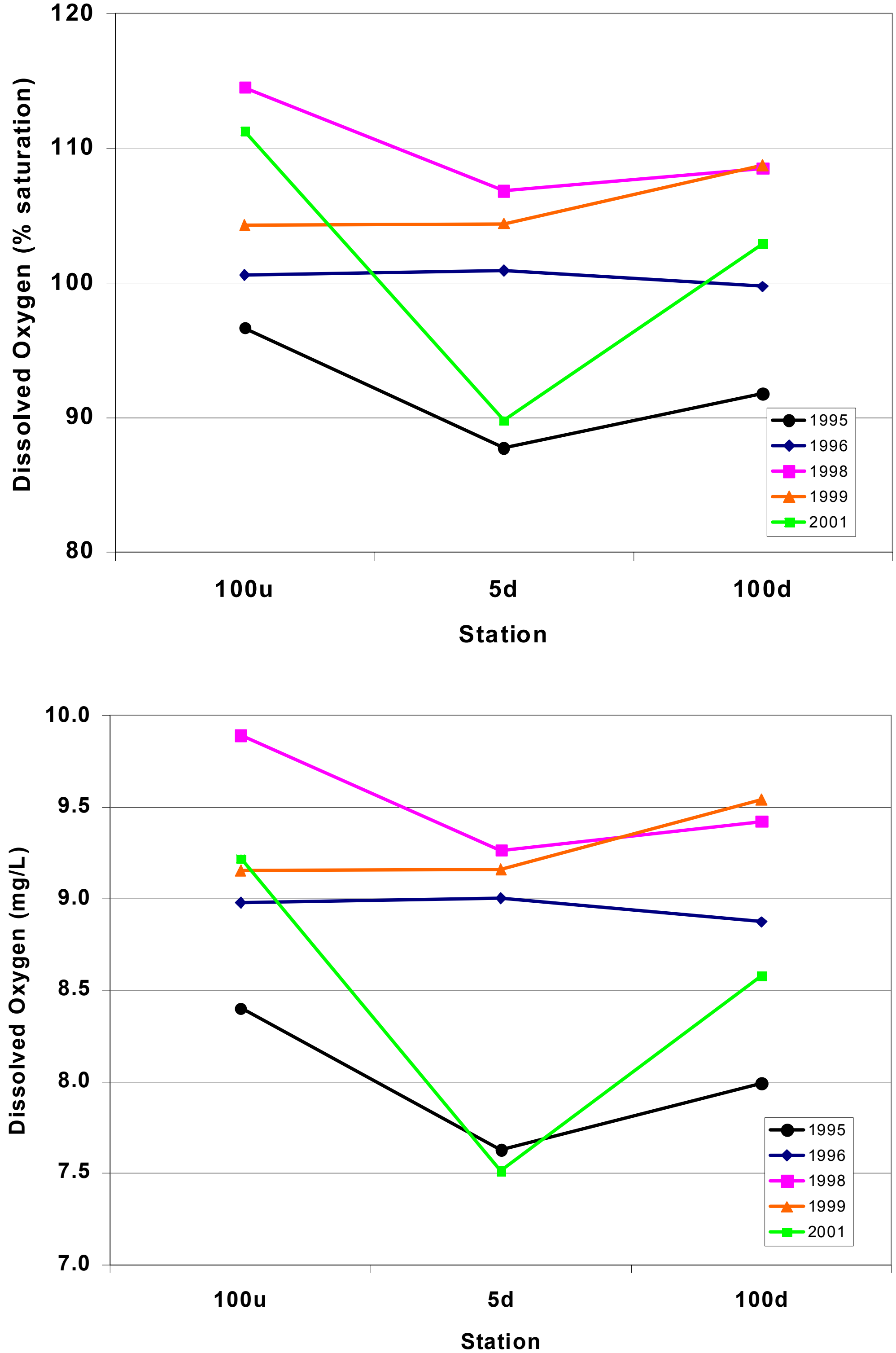


FIGURE 3-4. SURFACE DISSOLVED OXYGEN CONCENTRATION (MGL^{-1}) AND PERCENT SATURATION AT TISF-HT FROM 1995 TO 2001

In addition to comparing DO levels at stations upstream and downstream of the pens, we also looked at the interannual variability at four sites (ASMI-CI, BPFI-BE, CONA-SB, and TISF-HT) and compared these data sets against DO at control sites. The Ruth Point (Machias Bay) and Birch Pt/Gove Pt (Cobscook Bay) control sites were used for these comparisons because of their vicinity to 3 of the 4 time series sites and the availability of data for 4 of the 5 years of monitoring. No control data are available for Blue Hill Bay for comparisons against the TISF-HT data.

As mentioned previously, site configurations change (physically and stocking) from year-to-year and this results in variations in the sampling schema used each year. Graphical examinations of the time series at these four sites suggest that interannual variability in DO levels is comparable to and often greater than the variability across sampling locations for a given year. As seen at TISF-HT, the range in DO values at each sampling location varies over a 2 mgL^{-1} range, which is comparable to the range in value that were observed across these stations in 2001 (Figure 3-4). Similar interannual and annual variability were observed at the other three sites, but due to the multiple stations at 5 and 100 m downstream, the trends are not as clear as shown for TISF-HT. Some commonality in DO interannual trends was observed across the four sites with 1995 having relatively low DO levels and 1998 having high levels. At TISF-HT and ASMI-CI, 2001 also exhibited lower DO levels, while further to the east in Cobscook Bay BPFI-BE and CONA-SB had higher levels in 2001 and lower DO in 1999. These trends tended to hold true at both upstream and downstream sites. One obvious difference was at ASMI-CI in 1998 where high DO concentrations were measured at the 100 m upstream station and one of the 5 m downstream stations (similar to the high levels seen at the other three sites), but low concentrations were observed at the other 5 m downstream station and the 100 m downstream station. These were the only sampling locations where DO percent saturations levels of <85% were measured in 1998.

The 100 m upstream stations were designed to be measures of ambient conditions, but due to the complex currents and tidal mixing along the coast of Maine some have suggested that even these stations may be influenced by aquaculture activities. To examine this and to attempt to tease out information on the effect of changes in ambient DO levels have on the site data, we compared ASMI-CI, BPFI-BE and CONA-SB data against coincident data from Ruth Point and Birch Pt/Gove Pt control sites (Figure 3-5). Since this comparison was across years, the data for 5 and 100 m downstream sampling stations were averaged for each of the sites. For the four years worth of data for each comparison, there were no significant differences (P>0.1) in surface DO concentration or percent saturation between the control site and any of the sampling locations. The control site data were often comparable or lower that the 100 m upstream and downstream stations and in 1998 at or below levels seen at the 5 m downstream stations at each of the three sites (Figure 3-5). These results suggest that (1) regional variations in DO might be driving some of the variability that is being observed in the FAMP site data, (2) in some instances it may be a mistake to attribute lower DO levels to aquaculture activities (at ASMI-CI in 1998 for example), and (3) that we may need to reevaluate the location of the reference sites.

The Birch Pt/Gove Pt control, BPFI-BE, and CONA-SB sites were correlated with respect to interannual trends. These three sites are also in close proximity and are in the same geographic area of upper Cobscook Bay. The Birch Pt/Gove Pt site appears to be a good reference site and indicator of ambient DO levels. The situation in Machias Bay, however, appears to be more complex both between the ASMI-CI and Ruth Point site and within the aquaculture site itself. As shown in Figure 3-2, the ASMI-CI site covers a large area and its configuration is complex. This coupled with the interannual variations in sampling schema based on prevailing currents and pen stocking makes interannual comparisons difficult and perhaps fruitless. The distance between ASMI-CI and Ruth Point sites and the differences in geomorphology at the two sites suggests that we should not expect interannual trends in DO to be correlated and that a different reference site may be needed for comparisons in Machias Bay. Note that there are other control sites in the bay, but they have not been sampled on a consistent basis.

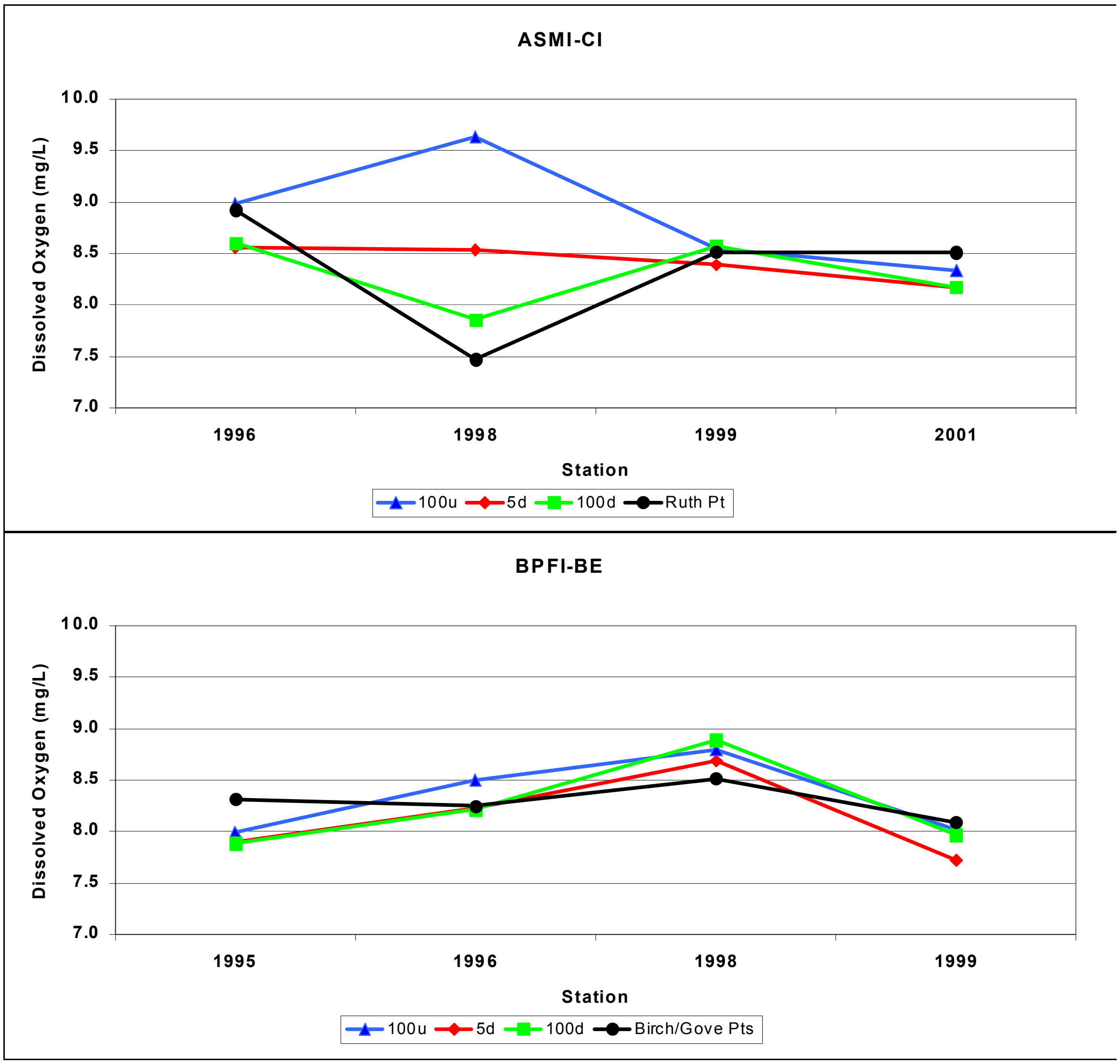


FIGURE 3-5. SURFACE DISSOLVED OXYGEN CONCENTRATION (MGL^{-1}) AT ASMI-CI, BPFI-BE, AND CONA-SB AND CONTROL SITES FROM 1995 TO 2001

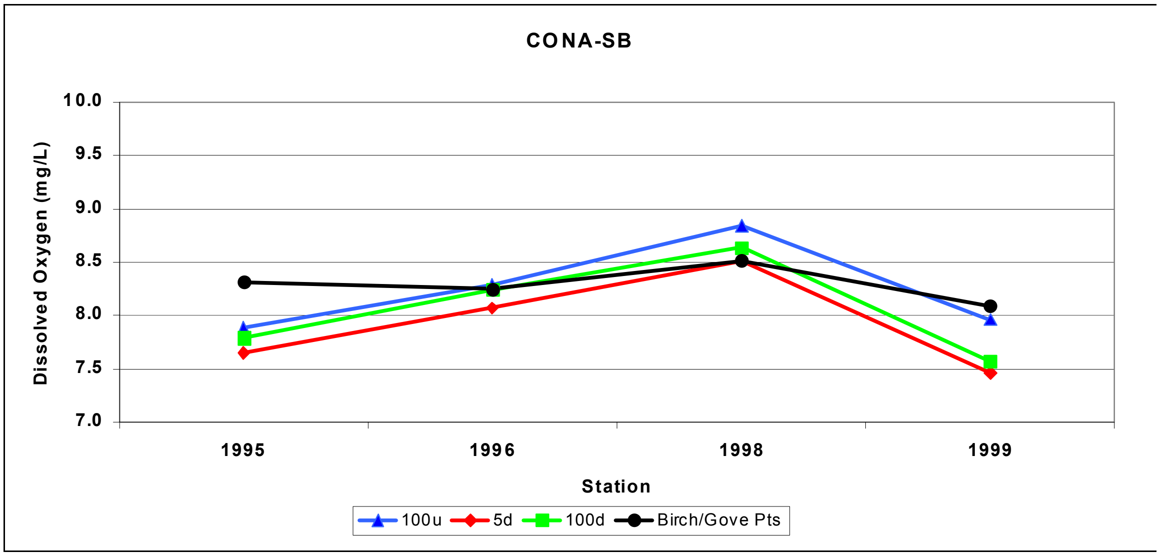


FIGURE 3-5 (CONT'D). SURFACE DISSOLVED OXYGEN CONCENTRATION (MGL^{-1}) AT ASMI-CI, BPFI-BE, AND CONA-SB AND CONTROL SITES FROM 1995 TO 2001

3.2 BENTHOS

3.2.1 Benthic Infauna

Data Review

Data from 35 sites were reviewed to determine which sites had the longest time series of consistently collected benthic data (Table 3-1). Data collected from 1991 through 1994 were not included because of changes in FAMP protocol that were implemented in 1995. An increase in the mesh size used (0.5 mm to 1.0 mm) to wash bottom sediments from benthic samples coupled with identification of organisms to the family level, rather than the species level, led to a significant reduction in the total abundance and slightly reduced the species richness (Heinig 2000a). In practice, most organisms were identified to the species level, and all *Capitella capitata* and *Mediomastus ambiseta* were identified to species level as indicated by the species lists from annual reports (Heinig 2000b). Site maps were reviewed to determine the exact location of the infaunal samples with respect to net arrays. Because of changing husbandry practices, especially improvements in pen design and refinement of net pen orientation to currents and the fact that most of Maine's aquaculture leases were issued prior to 1997, a limited number of stations — only 10 of the 35 sites — had at least three years of benthic data and were collected in the same location within the site (Table 3-4). None of these had baseline data that were comparable to post-1997 data.

A database was created for the subset of 10 farms selected for analysis. The data were further reviewed to examine the locations of benthic samples with respect to the net pens. Only samples collected at 0, 30 and 60 meters upstream and downstream of a cage system were included (Table 3-4). Although some samples were also collected at other distances, they were not included in the analysis.

Field and Laboratory Methods

From 1995 through the present, single sediment cores were taken in the fall of alternate years at pre-selected stations using 4-in. diameter PVC pipe coring devices inserted to a depth of 10 cm or to resistance, whichever was first. Divers took a single core sample at stations located upstream of a cage system at 60 m, 30 m, and 0 m and downstream at 0 m, 30 m, and 60 m. Samples were washed through a 1.0 mm mesh sieve and preserved using standard techniques (Heinig 2000a). Organisms were identified and counted.

The original monitoring program, prior to 1995, used 0.5 mm mesh sieves, and identification was to the lowest possible taxon, usually species. Analyses also included sediment grain size, total organic carbon, and measurement of the depths of both the unconsolidated sediment layer and reduction-oxidation potential (RPD) layer. These analyses showed no relation to observed changes in the benthos, and were dropped in the fall of 1996 (Heinig 2000a).

Analytical Methods: Analysis of Variance

The central question of whether the FAMP program is meeting regulatory objectives was further refined to whether measured parameters allow an assessment of regulatory compliance (i.e., “no unreasonable impact to the balanced indigenous benthic community”).

These questions were developed further into a null hypotheses:

- Ho: No difference in parameters between “within pen” (0 m), and “nearfield” (i.e., 10 and 30 m from the pen),
- Ho: No difference in parameters between upstream and downstream locations,
- Ho: No difference in parameters between farms, and
- Ho: No relationship between benthic parameters and production.

These questions/hypotheses were approached with standard analysis of variance techniques of community parameters (abundance, richness, diversity, percent *Capitella capitata*) to determine whether there are significant differences among farms, years and locations. Standard community analysis techniques (numerical classification) were used to determine whether there are differences in community structure with respect to location, year, and distance.

Analysis of variance (ANOVA) was performed on the community metrics reported by Heinig and Bohlin 1996, and Heinig 1997, 1998, 1999, 2000b, 2001, which include taxa richness (number of taxa), total abundance (total organisms/0.1 square meter), relative diversity (Shannon and Weaver 1949), and percentage of the indicator species, *Capitella capitata*. These metrics are considered useful indicators of environmental “health.” In marine and estuarine habitats, a degraded benthic community is typified by low numbers of taxa, low relative diversity, and high proportions of opportunistic species. *C. capitata* is a reliable indicator of degraded conditions. Abundance is sometimes very high, dominated (or “hyperdominated”) by *Capitella.* These conditions are also referred to as “stage 1” or pioneering (Rhoads et al. 1978; McCall 1977), where benthic species are dominated by small, surface dwelling organisms that are resistant to environmental stress and resilient recolonizers following a disturbance. The other end of the spectrum is Stage 3, or equilibrium*,* which represent as more mature successional stage. This stage is typified by high numbers of taxa, high relative diversity, larger, a predominance of large, deep dwelling benthic fauna, and low proportions of opportunistic species such as *C. capitata.*

Since the database was unbalanced, the General Linear Models (GLM) procedure in SAS software was used (SAS 1985). A mixed model ANOVA was used based on reviews by Underwood (1994) and Stewart-Oaten et al. (1986) Distance from the edge of cage (0 m, 30 m, and 60 m) and location (Upstream and Downstream of the cage system) were considered fixed effects because the stations were pre-selected. Year and site (farm) were considered random effects because both the biennial fall sampling dates and sites represented only a fraction of all possible dates and sites (Underwood 1994). The mixed effects ANOVA model was used to test the null hypothesis that the differences between stations were not significant (p>0.05). The ANOVA model analysis was performed on data from single samples taken from at least three different years at a single farm for each of the ten farms (Table 3-5). Next, the data were pooled for all ten farms (Table 3-6) that increased the degrees of freedom of the error term and increased the sensitivity of the model and reduced the probability of making a Type I Error (falsely rejecting the null hypothesis).

TABLE 3-4. FARMS SELECTED FOR STATISTICAL ANALYSIS OF BENTHIC DATA

Site	Alternate name	Location	Years	File Specifics
ASMI CI		Cross Island	96,98,00	"c" farm only
CONA SB		South Bay, Gove Pt.	97,99,00	CONA SB2 97,CONA SB99,CONA SB South inside 00
DESC LU	STEV LU	Johnson Bay "Lubec"	95,98,00	
IAFI PC	MAFI PC	Prince Cove	95,98,00	MAFI PC 95, 98,00
LREN TE	COOK TE,ECFF TE	Treats Island	95,98,00	ECFFTE 95, COOK TE 98, LRENTE inside
MCNC CH		Cutler Harbor	95,97,99,00	MCNC CH 95,97,99,00
MCNI SI	RLLT SI	Spectacle Island	95,97,99,00	RLLT SI 95,97,99,00
SFML JB3		Johnson Bay	95,97,99	Use middle pens
SFML RN		Rogers Island	95,97,99	SFML95,97,99
TIFI TW1		Treats Island	95,98,00	Delete polar samples, keep steel samples for 00

Results: ANOVA

Richness

Our assessment of ANOVA focuses on the ANOVA incorporating all farms (Table 3-6) because the model was significant. However, significant differences in the main effects must be considered trends because of the significant interaction terms, which are not included in Table 3-6. Significant differences in number of taxa were detected among farms, years and distance (Table 3-6). In addition, the interactions of farm and location and farm and distance were significant. Interpretation of these significant interactions is difficult, given that complexity of the resultant matrices (10 farms, 2 locations, and 3 distances). Some general trends were noted. IAFI PC (12 taxa per core, an average over all years, distances, and locations) and DESC LU (9) had much higher numbers of taxa than remaining farms. ASMI CI had much lower numbers of taxa (4 taxa per core). Over all farms, numbers of taxa were higher at 30 and 60 m distances than at zero distance. However, these results can be considered only a trend given the significant interactions.

Farms differed in terms of trends in number of taxa (Table 3-6), which does not include the significant interaction terms). For example, farms with upstream/downstream differences included IAFI PC, DESC LU, LREN TE, SFML RN. Farms with no difference in number of taxa between 0, 30 and 60 included TW, IAFI PC, DESC LU, LREN TE. Farms with no difference in number of taxa between 0 and 30: SFML RN and CONA SB

Abundance

Analysis of Variance results for total abundance showed significant differences among farms, locations, with significant farm X location interaction (Table 3-6). Geometric mean abundance was significantly higher at IAFI PC (1862 per 0.1 square meter, averaged over all years, locations, and distances); MCNI SI (75 per 0.1 square meter) and MCNC CH (46 per 0.1 square meter) had the lowest abundances. Abundance was significantly higher at upstream locations compared to downstream locations. No significant differences were detected among distances or years. When the significant Farm X Location differences were examined, IAFI PC (upstream and downstream), DESC LU and LREN TE upstream were significantly higher than remainder. MCNI SI (upstream and downstream) had the lowest abundances.

Diversity

Analysis of variance results for H' species diversity had significant differences among distances, with 30 and 60 m significantly higher than 0; however, interactions with farm were significant (Table 3-6). There were no significant differences in location or year.

Percent Capitellidae

Analysis of variance of percent Capitellidae revealed significant differences among distances and years. The interactions between farm and distance, farm and location, and farm, location, and distance were significant, complicating the interpretation of the main effects. Percent Capitellidae was significantly higher immediately adjacent to the site in comparison to 30 and 60 m distant.

Conclusions

A key question is whether multiple-year comparisons are important to meet regulatory requirements. For example, does it matter if the site is changing over time? Or, is it more important the site remain within absolute defined conditions. If change over time is important, then quantitative statistics such as ANOVA are important. ANOVA may not be appropriate to discern differences in metrics unless replication is added so that the number of samples increases from one to at least three.

In the current FAMP program, the lack of replication forced the use of another variable as a replicate (in this case, farm). The results were difficult to interpret because of the significant interactions. ANOVA for each farm lacked replication, resulting in poor model fit. The use of quantitative statistics in the future will require replication. Nonparametric one-way ANOVA would be an alternative in cases where there is no replication, and could be used to test differences among one of the class variables

A second analytical challenge was the variable sampling design. For example, the distances that samples were collected for both upstream and downstream locations varied from year to year as a result of changing net pen configurations and a shift in emphasis toward nearfield monitoring. If statistics are to be used, samples must be collected according to a consistent sampling design.

TABLE 3-5. SUMMARY OF ANOVA RESULTS FOR BENTHIC SAMPLES FROM INDIVIDUAL FARMS FROM 1995 THROUGH 2000

Number of Taxa

Farm	Model	df Error	Location	Distance	Year	Loc x Dis	Multiple Comparison[1]
ASMI CI C	NS	8	NS	*	NS	NS	30 0 60 0 60 Scheffe
CONA SB	*	7	NS	NS	NS	NS	
DESC LU	*	3	**	NS	*	NS	
IAFI PC	*	7	*	NS	*	NS	Up > Dn Scheffe
LREN TE	*	6	NS	NS	NS	NS	
MCNC CH	NS	7	**	**	NS	NS	
MCNI SI	NS	9	NS	NS	NS	NS	
SFML JB	*	3	NS	NS	NS	NS	
SFML RN	*	7	*	**	NS	NS	Up > Dn 60 > 30 0 Scheffe
TIFI TW	***	8	NS	NS	**	**	60-U 30-U 0-D 60-D 30-D 0-D

Log (x+1) transformed abundance

Farm	Model	df Error	Location	Distance	Year	Loc x Dis	Multiple Comparison[1]
ASMI CI C	NS				**		
CONA SB	*	7	NS	***	*	NS	30 0 60 Descending
DESC LU	*	3	***	*	**	NS	u>d 30 0 60 Waller 30 0 60 Scheffe
IAFI PC	**	7	NS	NS		*	
LREN TE	NS						
MCNC CH	NS						
MCNI SI	NS						
SFML JB	NS						
SFML RN	*		NS	NS	NS	NS	
TIFI TW	*		NS	NS	**	NS	

Relative Diversity

Farm	Model	df Error	Location	Distance	Year	Loc x Dis	Multiple Comparison[1]
ASMI CI C	NS	2					
CONA SB	NS						
DESC LU	NS						
IAFI PC	NS						
LREN TE	NS						
MCNC CH	*	6	NS	*	NS	NS	60 30 0 Scheffe
MCNI SI	NS						
SFML JB	NS						
SFML RN	**	7	NS	NS	NS	NS	30-D 60-D 30-U 0-U 60-U 0-D
TIFI TW	NS						

[1] In descending order

Distance = distance from the edge of cage (0 m, 30 m, and 60 m); location = Upstream/ Downstream of the cage system.

TABLE 3-6. ANALYSIS OF VARIANCE RESULTS FOR ALL FARMS FOR METRICS DERIVED FROM SINGLE CORE SAMPLES OF BENTHIC INFAUNA TAKEN IN THE FALL OF ALTERNATE YEARS FOR A MAXIMUM OF THREE YEARS 0, 30, AND 60 METERS UPSTREAM AND DOWNSTREAM OF A CAGE SYSTEM

Metric	Source of Variation	df	MS	F	Multiple Comparison NOTE (ranked in decreasing order)
No. taxa	Farm	9	603.8	4.08**	PC LU RN TW TE JB SB CH SI CI
	Location	1	446.3	3.95NS	----------------------------
	Distance	2	257.5	4.71*	60 30 0 -------------------
	Year	5	232.9	7.58***	1995 1998 2000 1997 1999 1996
	FarmXLoc X Dis	15	22.0	0.72NS	
	Loc X Distance	2	78.7	3.47NS	
	Farm X Loc	9	126.4	5.71***	
	Farm X Distance	17	57.1	2.57*	
	Error	77	30.7		
Model *** , probability of a greater F 0.0001					
					(PC LU RN JB TE TW CH SB SI CI)
Abundance	Farm	9	2.64	6.89***	-------------------------------
	Location	1	3.19	11.22***	Up > Down ----------------
	Distance	2	0.15	0.72NS	
	Year	5	0.68	2.27NS	
	FarmXLoc X Dis	15	0.10	0.32NS	
	Loc X Dist	2	0.05	0.49NS	
	Farm X Loc	9	0.29	2.88*	
	Farm X Dist	17	0.20	1.99NS	
	Error	77	0.30		
H' Diversity	Farm	9	0.16	0.87NS	(CI TW SB LU TE PC RN JB CH SI)
	Location	1	0.02	0.09NS	
	Distance	2	0.47	8.56**	30 60 > 0
	Year	5	0.08	1.70NS	
	FarmXLoc X Dis	15	0.04	0.81NS	
	Loc X Dist	2	0.01	0.15NS	
	Farm X Loc	9	0.18	4.72**	
	Farm X Dist	17	0.06	1.44NS	
	Error	71	0.06		
% Capitellidae	Farm	9	0.16	0.65NS	(CH SI SB PC RN TE JB CI LU TW)
	Location	1	0.00	0.00NS	
	Distance	2	1.63	12.88***	0 > 30 60
	Year	5	0.20	3.53**	
	FarmXLocXDist	18	0.13	2.98**	
	FarmXDist	2	0.02	0.44NS	
	FarmXLoc	9	0.18	4.08**	
	Error	76	0.06		

Note: Among farm multiple comparison are not significant but included to show relative ranking.
Model *** Pr > F 0.0002; Distance = distance from the edge of cage (0 m, 30 m, and 60 m); location = Upstream/ Downstream of the cage system.

Numerical classification

Numerical classification (cluster analysis) was used to describe community composition (Boesch 1977). Bray-Curtis similarity matrices were calculated on log-transformed abundances. The frequency of occurrence of all taxa at each was reviewed in order to select a representative subset to include in the analysis. Taxa with at least 4 percent frequency of occurrence (i.e., 3 occurrences in 77 entities or at more than once in the three-year period) were included in the analysis. Several separate community analyses were developed, including one with all year-farm-distance-location combinations, one for each individual farm, and one averaging upstream/downstream locations. The latter is presented here (Figure 3-6).

Review of the dendrogram revealed six distinct groups formed by numerical classification. Group 1 was separated from the remainder of the entities at approximately the 10% similarity level, with a within-group similarity of approximately 20%. The community typified by Group 1 was composed of samples collected at MCNC CH, MCNI SI and ASMI CI, most from 30-60 m distance. Polychaetes *Nephtys* sp. and *Ampharete acutifrons* were the dominants, but the group had low total abundance and taxa richness (Table 3–7). Group 6, separated from the remaining groups at approximately 17.5% similarity, was a loose agglomeration of samples as indicated by the relatively small difference between the between-group and within-group similarities. They included CONA SB and MCNI SI, most at 30-60 m distance, along with ASMI CI, SFML JB3, and TIFI TW and MCNI SI at 0-m distance. Taxa richness and abundance was low, dominated by *Capitella capitata* and *Nereis* sp.

Groups 2, 3, 4, and 5 separated at approximately 25% similarity. Groups 2 and 3 showed very little difference in between and within similarities, suggesting communities were not very distinct. Group 2 was composed of samples mainly collected in 2000, including DESC LU and IAFI PC (all distances) as well as from LREN TE (0, 30 m), TIFI TW (30, 60 m) and CONA SB (0 m). The benthic community typified by Group 2 samples included low abundances of polychaetes *Mediomastus ambiseta,* Terrebellidae, and Ampharetidae (Table 3-7). Group 3 samples were dominated by Ampharetidae (including *Ampharete acutifrons*), *Capitella capitata,* Nematodes, and *Polydora* spp. Group 3 samples included samples mainly from 1995, 1996 and 1997 from IAFI PC, SFML RN and TIFI TW. Only 3 samples composed Group 4: MCNC CH, SFML RN and SFML JB3 at 30 m collected in 1995, 1997 and 1999 respectively. The benthic community typified by Group 4 samples had moderate abundance and taxa richness and was predominantly composed of *Capitella capitata*, along with *Ophelina acuminata* The 25 samples composing Group 5 included many of the near-pen samples (0 distance). Hyperdominance of *C. capitata* typified the benthic community in this group. The main difference between the community at Group 5 and Group 3 was the abundance of *C. capitata,* an order of magnitude higher in Group 5.

Numerical classification is a useful tool for describing the benthic community It provides additional information beyond the benthic metrics of abundance, taxa richness, H' diversity and percent Capitellidae. For example, the benthic community at DESC LU and IAFI PC in 2000 (Group 2) was similar regardless of distance from the pen, but had relatively low abundance. The benthic community at IAFI PC in 1998 and CONA SB in 1997 (Group 5) was also similar regardless of distance, but was characterized by dominance by *Capitella capitata.* Results of the community analysis allow generalizations about the benthic community and the degree of impairment over time and space and across farms.

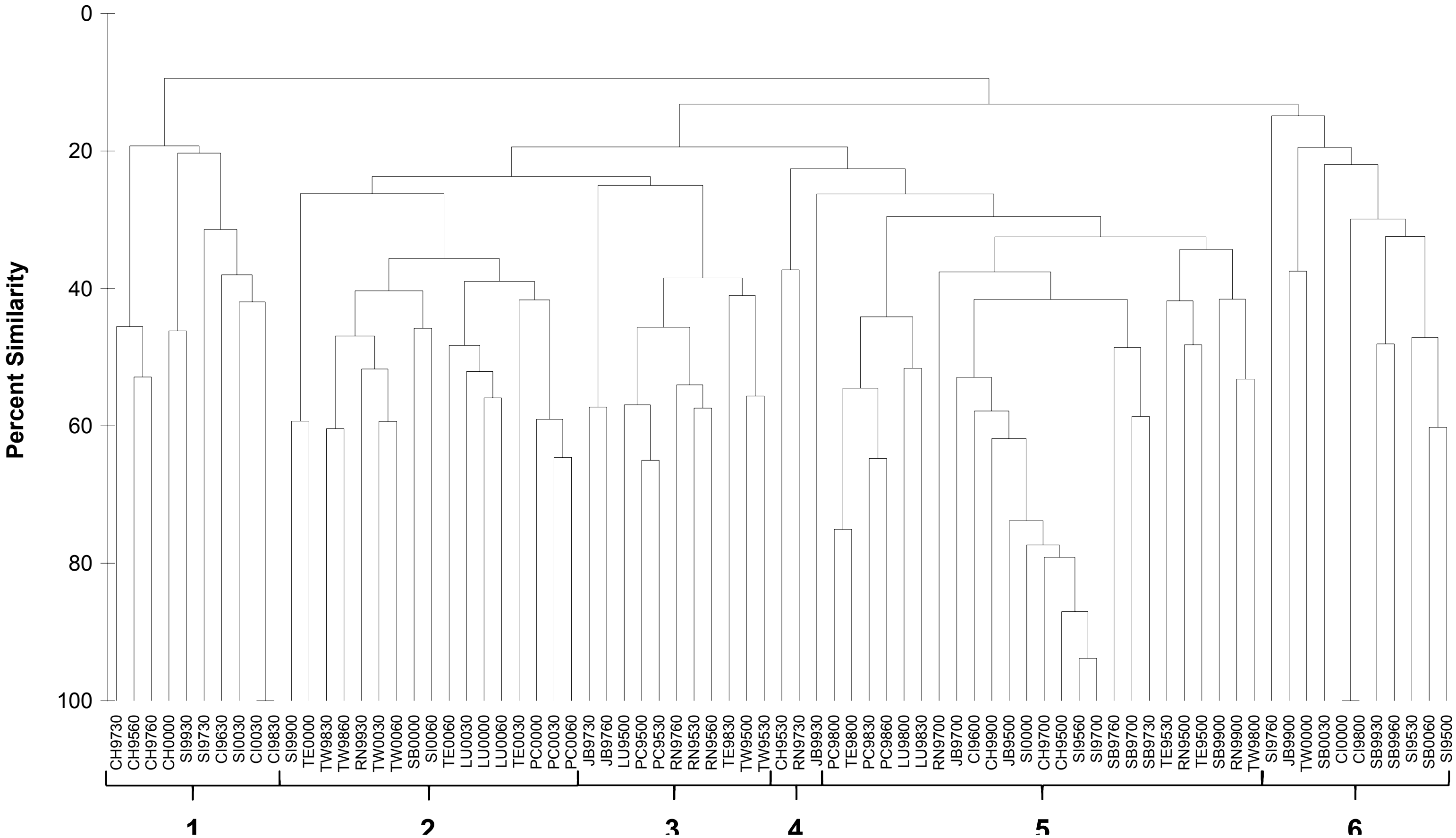


FIGURE 3-6. DENDROGRAM FORMED FROM NUMERICAL CLASSIFICATION OF FARMS, YEARS AND DISTANCES (UPSTREAM AND DOWNSTREAM LOCATIONS AVERAGED). NOTE: FIRST TWO CHARACTERS REPRESENT FARM, SECOND TWO CHARACTERS REPRESENT LAST 2 DIGITS OF YEAR SAMPLED, AND LAST TWO CHARACTERS REPRESENT DISTANCE IN METERS FROM NET BOUNDARY.

TABLE 3-7. GEOMETRIC MEAN ABUNDANCE FOR THE 10 MOST ABUNDANT TAXA IN EACH GROUP DEFINED BY NUMERICAL CLASSIFICATION

Taxon	**Group**					
	1	**2**	**3**	**4**	**5**	**6**
Nephtys sp.	1.4	0.7				
Ampharete acutifrons	0.9		3.7	0.7	0.1	
Aricidea spp.	0.4	0.7		0.2		
Nucula delphinodonta	0.3		0.3	0.3	0.0	0.1
Nucula proxima			1.2	0.1	0.2	0.4
Aglaophamus nectenus	0.3					
Ampharetidae	0.2	1.9	3.0		0.2	
Nereis spp.	0.2	0.1	0.3	0.3	0.6	0.5
Capitella capitata	0.1	1.8	4.5	4.0	40.7	0.8
Scoloplos sp.	0.1		0.3		<0.1	
Mediomastus ambiseta		2.2	0.5		<0.1	<0.1
Terrebellidae		2.1	0.2	0.3	0.2	0.2
Nematoda		1.5	3.5	1.0	3.5	0.8
Phyllodocidae		1.4	0.1		0.6	0.4
Ninoe nigripes		1.1	0.6	0.5	<0.1	<0.1
Ophelina acuminata		1.0	1.0	1.2	0.2	<0.1
Polydora spp.		0.9	3.2	0.3	0.4	0.0
Phloe minuta		0.4	2.6	0.3	0.3	
Asabellides oculata	<0.1		2.2			
Prionospio steenstrupi		0.6	2.1		0.1	
Terrebellides stroemi	<0.1	<0.1	1.8		<0.1	
Corophium spp.			1.7		<0.1	
Tharyx spp.			1.6		0.3	
Buccinum undatum			0.2	1.5	0.1	
Mytilus edulis	0.1	0.1	0.2	1.3	0.2	
Hiatella arctica		<0.1	0.1	0.8	<0.1	
Nemertinea		0.3	0.2	0.7	0.4	
Spio setosa		0.5				0.2
Cistena granulata		0.5	0.7		0.3	0.1
Thyasira gouldii		0.4	1.2	0.4	0.1	0.1
Pherusa spp.		0.1	0.3			0.1
Total abundance	**5.2**	**25.8**	**59.2**	**16.7**	**54.4**	**3.6**
Number of taxa	**26**	**55**	**66**	**27**	**68**	**24**

3.2.2 Video Review

Benthic monitoring includes semi-annual video monitoring. The goal of video recording is "to provide those unable to dive beneath the cages with visual images of conditions adjacent to and beneath cages systems, as well as provide an objective, rapid, albeit superficial means of documenting and evaluating changes in conditions beneath and adjacent to cage systems" (Heinig 2000a). Video recording is performed by divers along a 60 m transect line established at both the upcurrent and downcurrent ends of the cage systems as well as adjacent to or beneath the cages. Diver observations augment the video recording. Results of the survey are reported semi-annually and include either narrative summary (prior to 1995) or graphical representation, beginning in spring 1995. Beginning in

1999, spring video monitoring was dropped from many (but not all) of the sites that in the previous fall review did not evoke concern and posed no additional risk. Sites that had been harvested off, for example, fell under this category.

Video monitoring provides a rapid, relatively inexpensive method to document conditions under and adjacent to the pens. This is particularly useful to identify incipient degradation or an impaired benthic community using indicators such as accumulated feed, *Beggiatoa* colonies, and fouling from nets and other debris. The question we attempted to address is: *How do results from video recordings compare to results from benthic sampling*? We compared video results to results from benthic samples, using number of taxa and percent Capitellidae as indicators of benthic health. We looked at only those video summaries that also had accompanying benthic samples, using the subset selected for statistical analysis. Video graphics from annual reports (Heinig and Bohlin 1996; Heinig 1997,1998,1999 2000b, 2001) were reviewed in the locations where benthic samples were collected. These locations were assessed as to presence of degradation indicators (feed deposition, presence of *Beggiatoa* [with or without gas, trash, or nets]) and a qualitative assessment of epifaunal community "diversity"(at least 5 or more taxa indicative of "high" diversity; a somewhat arbitrary number based on a review of the range in species visible on video graphics). Benthic infauna samples from the annual reports (Heinig op.cit.) were assessed in terms of number of taxa (low=0-10 taxa; moderate=11-20 taxa; >20= high, the categories based loosely on ANOVA results) and percent Capitellidae (0-20%=low; 21-50= moderate; >50=high, again loosely based on ANOVA results). Results are presented in Table 3-8.

In most cases, visual indications of an impaired benthic community coincided with a depauperate benthic infaunal community and, in some but not all cases, moderate to high proportions of Capitellidae. High numbers of epifaunal taxa in video observations was not a reliable indicator of infauna results . DESC LU and IAFI PC were exceptions in 1995, where taxa richness was high and percent Capitellidae was low to moderate despite the presence of *Beggiatoa* and food deposition. And the converse occurred where some sites had low numbers of taxa despite the lack of indicators of salmon farm impacts. ASMI CI in 2000 and LREN TE in 1998 and 2000 are examples of sites with low numbers of taxa despite the absence of degradation indicators. Low numbers of taxa may reflect factors other than degraded environmental conditions. A high energy habitat, recent meteorological disturbance such as storms, sediments texture, natural patchiness, and even predation by epifauna can also account for lower than expected numbers. .

Video monitoring is an important part of the FAMP monitoring program and should be continued. Video has a rapid response time and covers a larger area than benthic infauna sampling. Video showed good agreement with infauna in most cases. Further investigation may be able to factor in other environmental variables (substrate, hydrodynamic characteristics) that may be contributing to observed trends, improving the linkage with infauna results, and ultimately allowing its use as a "Tier 1" sampling method.

TABLE 3-8. COMPARISON OF INDICATIONS OF IMPAIRMENT FROM VIDEO RECORDINGS AND RESULTS FROM BENTHIC INFAUNA SAMPLES

		Video Observations[1]		Infauna Results[2]		
Farm	**Year**	**Impairment Indicators**	**Community Diversity**	**Number of Benthic Taxa**	**Percent Capitellidae**	**Comments**
ASMI CI	1998	Food, nets, trash, barren bottom	High	Low	High	Good agreement
	2000	"Decaying", trash	High	Low	Low-High	Diverse epifauna despite low numbers of infauna
CONA SB	1997	*Beggiatoa*, pimpled bottom, evidence of deposition	High	Low-moderate	Low-High	Upstream/downstream differences in benthos, not reflected in video
	1999	*Beggiatoa*, anoxia, nets, trash	High	Low	Low-High	Diverse epifauna despite low numbers of infauna
	2000	No impairment indicators	Low-High	Low-moderate	Low	Diverse epifauna, low number of benthic taxa
IAFI PC	1995	*Beggiatoa,* nets, trash	High	High	Moderate	High richness despite presence of *Beggiatoa*
	1998	Food, barren deposition, trash, feces	High	Low	Moderate-High	Good agreement
	2000	No impairment indicators	High	Moderate	Moderate	Sandy sediment w/ shell hash, possible high energy environment
MCNI SI	1995	*Beggiatoa* w/gas	Low	Low	None-High	No. taxa agrees with indicators
	1997	*Beggiatoa* w/gas	Low	Low	None-100%	No. taxa agrees with indicators
	2000	*Beggiatoa* w/gas	Low	Low-moderate	High	Sandy sediment w/ shell hash, possible high energy environment, and higher no. of taxa
DESC LU	1995	*Beggiatoa*	Low	High	Low-moderate	High richness with gravel/rock, likely high energy environment
	1998	Accumulated food, nets	High	Low-moderate	Moderate-High	Depositional, with reduction in no. taxa

TABLE 3-8. COMPARISON OF INDICATIONS OF IMPAIRMENT FROM VIDEO RECORDINGS AND RESULTS FROM BENTHIC INFAUNA SAMPLES (CONT'D)

		Video Observations[1]		Infauna Results[2]		
Farm	**Year**	**Impairment Indicators**	**Community Diversity**	**Number of Benthic Taxa**	**Percent Capitellidae**	**Comments**
LREN TE	1995	*Beggiatoa,* nets, trash	High	Low-moderate	Moderate	Moderate-high no. of taxa, despite indicators, likely due to sandy sediment w/ shell hash, possible high energy environment
	1998	*Beggiatoa,* nets, tires	Low-	Low-moderate	Moderate-High	Depositional, with reduction in no. taxa
	2000	Deposition, net	High	Low-moderate	Low	
MCNC CH	1995	*Beggiatoa,* food accumulation, diatoms, few other taxa	Low	Low-moderate	Low-moderate	Good agreement
	1997	*Beggiatoa,* deposition	Low	Low-moderate	High	Good agreement
	2000	*Beggiatoa,* deposition, decaying vegetation	Low-Moderate	Low	Low	Low abundance and diversity

[1]Community Diversity: High = At least 5 taxa visible from video; low = less than five taxa visible.
[2]Number of taxa: 1-10= Low, 10-20=Moderate, >20=High.
Percent Capitellidae: 0-20%= Low; 20%-50% = Moderate, >50%=High.

Linkage with Production

The relationship of salmon production was explored qualitatively and through the use of linear regression. Monthly production data by farm were provided by Maine DMR, which were totaled to obtain an annual production level. The number of taxa derived from benthic infauna sampling (an average of the samples collected at zero distance) was compared graphically as shown in Figure 3-7. There was a general trend of increasing number of taxa, typical of a Pearson-Rosenburg (1978) enrichment response, with production up to approximately 2.5 million pounds. However, there was no significant relationship of number of benthic taxa with annual production when tested with linear regression (F=1.86; df=20).

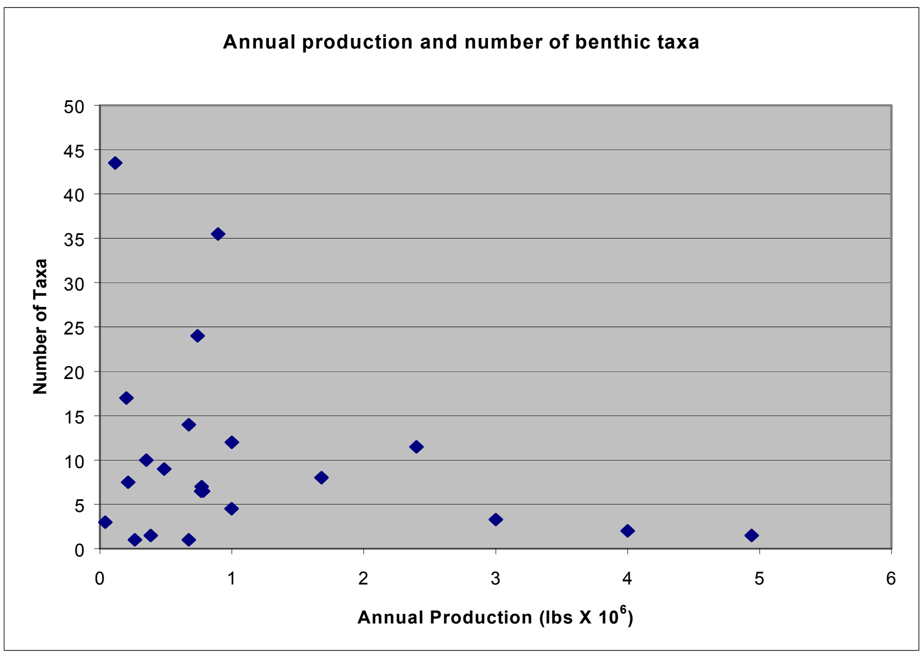


FIGURE 3-7. ANNUAL PRODUCTION (POUNDS X 10^6) AND NUMBER OF TAXA FOR SELECTED FARMS AND YEARS

4.0 TECHNICAL CRITIQUE

4.1 INTRODUCTION

A goal of the FAMP is to ensure that the State has an adequate tool to assess whether a finfish operation is meeting State water quality standards. Under MDEP Title 38 (Water Classification Program), the standards for Class SB waters state: "Discharges to Class SB waters shall not cause adverse impact to estuarine and marine life in that the receiving waters shall be of sufficient quality to support all estuarine and marine species indigenous to the receiving water without detrimental changes in the resident biological community. While the FAMP was designed to provide a general overview of conditions that could trigger additional monitoring, both the industry and the science have progressed to a point where the program may be refined to be more strategic. Because FAMP data may be used to support enforcement of state law, it must be scientifically defensible. The "scientifically defensible" aspect can be addressed through a logical experimental design and rigorous statistical analysis.

The current FAMP includes both water column and benthic monitoring. The water column program focuses on dissolved oxygen as the primary indicator of aquaculture's impact on water quality. The benthic program combines video monitoring and benthic infauna analysis to evaluate conditions within and outside of salmon pens. Our program review suggests that the State has an excellent program that rapidly assesses water quality compliance and provides evidence of degrading and degraded conditions within the pens. The current contractor has an extensive understanding of the industry and how it affects the marine environment. However, improvements to both the FAMP and regulatory framework should be considered.

The water quality program currently assesses conditions against the established State Standard for percent saturation of dissolved oxygen of 85% for the class SB waters. This is strictly a compliance monitoring assessment and does not attempt to evaluate the potential farfield impacts of nutrients and BOD. Thus, the FAMP, as it currently stands, can assess compliance with existing regulatory requirements during each survey. As these requirements may change with the issuance of new State and Federal permit guidelines, the FAMP will need to be modified to meet them. The State Water Quality Classification Standards (Title 38 Chapter 3 §465-B) also reference biological language and it seems imperative that some level of biological assessment be included in the monitoring program. Standards for SB waters specify that discharges "shall not cause adverse impacts to estuarine and marine life in that the receiving waters shall be of sufficient quality to support all estuarine and marine species indigenous to the receiving water without detrimental changes to the resident biological community." The benthic element of the existing monitoring program could fulfill its regulatory requirement by answering the following question: does the benthic community show evidence of significant changes from the indigenous community? However, interpretation is not easy without further defining the magnitude, quality, and spatial and temporal extent of acceptable change. These policy issues, if resolved, would guide refinement of the monitoring program.

Although it was not our charge to comment on the regulatory framework that will define the use of FAMP data, it is important to briefly discuss aspects of this as several areas of vulnerability relate to the program design. First, the assessment of impairment presently relies on "professional judgement." From a regulatory standpoint, there is some debate as to whether this is sufficient or numeric standards are warranted. From a litigation standpoint, "professional judgement" alone could be problematic. Ecologically meaningful criteria coupled with a quantitative assessment would reinforce the professional judgement. At least until now, the science has not supported development of ecologically meaningful criteria that would apply not only to the very complex coast of Maine but across discharge types. In other words, defining acceptable impact should apply equally to all activities and not simply finfish aquaculture.

However, regardless of impact criteria, the strength of the FAMP sampling design (and any other monitoring program) would benefit by incorporating some or all of the following elements to allow statistical testing:

- A standardized design, consistent over time and between farms, as much as feasible,
- Consistent methods for collection and analysis,
- Database with clearly defined structure,
- Baseline data,
- Reference data, and
- Replication within each cell.

4.2 WATER QUALITY

For water quality, the following questions were addressed:

- Does FAMP in its current form meet the requirements established by regulatory framework?
- As such, has FAMP provided data with which MDMR can adequately assess effects from aquaculture on the marine environment?
- Can FAMP provide data necessitated by current and future permit requirements?
- If not, but deemed necessary by MDMR, how can FAMP be modified to adequately address the current requirements and emerging water quality concerns?

4.2.1 Database Development and Management

In the process of conducting this review, it became apparent that the FAMP would benefit from the development of a database. Currently, water quality data are stored as the original SeaBird CTD files or as Lotus and Excel spreadsheets. In conductance of this review, a major data management effort was undertaken just to convert and load the data into an MS Access database in order to analyze a subset of the FAMP water quality data. Besides limiting the extent of the review, this level of data handling increases the potential for errors. Establishment of a FAMP database system would provide a program-wide integration of data loading, data queries, and downloads for analysis and synthesis. MDMR could manage and access data from collection, entry, and database loading to retrieval, distribution, and interpretive efforts. This would minimize data handling and manipulation errors as well as improve the efficiency of data review, analysis, and interpretation.

The database should be developed in easily utilized standard software. Consideration should be given to developing linkage with Geographic Information Systems and potentially developing a web-based system. One of the advantages of a GIS system is that it could incorporate the changing locations of net pens within the lease site. Stations should be named consistently throughout the program and should have geographic reference points within the database. A web-based database system would facilitate data entry (contractor or possibly site operators) and access (MDMR staff and other regulators). At a minimum, the database should include compile all past FAMP data (water quality and benthic), facilitate loading of new data, and allow for QA/QC procedures. The MDMR began development of just such a database in 2000 and expects it to be ready for use early in 2003.

4.2.2 Sampling Design

As discussed in Section 2.0, one of the most important aspects in assessing the impacts of aquaculture is the question of scale. Aquaculture impacts may occur on a variety of spatial and temporal scales – internal, local, and regional (Silvert 1992). The internal impacts are associated with dissolved oxygen reduction due to respiration. This impact is observed within and in the immediate vicinity of the pens and over a relatively short time frame – minutes to hours. These impacts are the focus of the FAMP water quality program. The discussion that follows focuses on the location of samples and the timing of collection.

The spatial scale used for compliance monitoring is essentially determined by the regulatory agencies governing the aquaculture industry. The MDEP general permit and the EPA Acadia permit as currently written use 30 m as the distance at which water quality standards must be met. This distance may change, but is basically based on an estimate of an appropriate mixing zone in which the facility should have minimal impact on water quality. The tidal currents along the Maine coast especially in Cobscook Bay make the one-size-fits-all mixing zone estimates difficult. The 30 m distance may change, but for this discussion and in the proposed changes to the FAMP (Section 5.0) the current mixing zone distance will be used.

As currently configured, water quality data are collected at 100 m upstream, 5 m downstream, and 100 m downstream. Given the complexity of the various sites and pen setups (see Figure 3-2), the FAMP contractor has collected samples in a loosely defined manner based on existing currents and pen layout. This often leads to odd sampling patterns with 100 m downstream serving as 100 m upstream for another set of pens, for example. A more structured setup would be useful both for those in the field and managers/regulators. In other states/provinces, the lease site boundary is used as the delineation of where water quality (and benthic) standards must be met. This is not an option in Maine given the size of the lease sites and the goal of minimizing environmental impacts. The current proposals expect that dissolved oxygen water quality standards are achieved within 30 m of the pens. Application of this standard based on individual pens, however, would be difficult given the varying configurations of the sites. We recommend a hybrid of the lease site and individual pen approaches. The mixing zone should encompass the entire footprint of the aquaculture facility and sample at intervals along a 30 m polygon, thereby establishing a clearer sample collection schema.

The current FAMP collected 5 m downstream samples and compared them against the standard of 85% DO percent saturation. As discussed in Section 3.0, there were very few instances (<5%) when the percent saturation standard was exceeded and even fewer (<1%; only 2 profiles) when the 100 m downstream samples were lower than 85%. It was this 100 m downstream sample location that was used to assess whether the site was in compliance with State water quality standards. The EPA site-specific permit for Acadia used the 100 m distance for compliance with standards. Essentially, the proposed MDEP general permit is using more stringent requirements by changing the 'compliance' distance from 100 m to 30 m. For continued comparison against historic FAMP data and to assess the extent of impact, we also recommend the continuation of monitoring at 100 m when a 30 m profile measures DO percent saturation <85%. This sampling should also be based along a polygon surrounding the existing aquaculture facility.

The effect of aquaculture on a regional level is not currently assessed by FAMP. In situ profile data are collected at a set of reference stations, but as discussed in Section 3.0, these stations are not necessarily comparable to lease sites. The objective for having reference sites is to compare the 30 and 100 m water quality data against representative ambient conditions. Thus, the reference sites need to be located close enough to the lease sites to be in similar waters, but far enough away to minimize sampling the same parcel of water. This distance would vary based on prevailing currents, but as an example a 10 cm/sec tidal current would displace a water mass 1.5 km in a 4-hour period. In Cobscook Bay, it would be difficult to find an area that meets these criteria. If the goal of the program is strict compliance monitoring, then the establishment of reference sites may be a moot point.

We recommend continued sampling at reference stations, but that the location of the stations needs to be reevaluated. Due to the constraints of tides and embayment size, the sampling of the same parcel of water may be difficult to eliminate, but could be minimized with appropriate planning and the collection of multiple profiles in several areas of the bays. A case could also be made that sampling to assess ambient conditions only becomes necessary if water quality standards were not met at the 30 and 100 m intervals. For the industry, however, it may be to their advantage to have studies conducted to assess what reference conditions are so that the natural occurrence of lower DO events are better understood.

In addition to evaluating water quality conditions over spatial gradients, the timing of sampling is also critical. FAMP requirements indicate that sampling should occur during "worst case" conditions, when feeding rates and water temperatures are highest. This overlap generally occurs between August and October. While feeding rates may actually peak in October, water temperatures peak in August. At the Portland NOAA buoy, historical data on sea surface indicate that temperatures drop from a mean of 16.4°C in August to 11.5°C in October. This, along with the increased mixing associated with fall storms and weakening of stratified conditions, suggest that sampling should occur in late August/early September rather than late September/early October.

The timing of the seasonal DO minimum varies annually in Gulf of Maine coastal waters. The Massachusetts Water Resource Authority (MWRA) outfall monitoring program conducts surveys every other week during the late summer and early fall to increase the likelihood of capturing the DO minimum. From 1992 to 2001, the seasonal DO minimum in Western Massachusetts Bay occurred as early as September 8 in 1999 and as late as October 29 in 1997 (Libby et al. 2002). It should also be noted that the magnitude of the DO minimum observed ranged from a low of 5.9 mg/L in 1999 to a high of 7.8 mg/L in 1993. The MWRA data indicate that the timing of the seasonal minimum can occur over at least a two-month timeframe and the magnitude of the DO minimum concentrations can vary by 2 mg/L.

Due to the conflicting influence of diurnal and tidal fluctuations on DO concentrations in coastal Maine waters (Kelly and Libby 1996), there does not appear to be any need to adjust the hours of sampling. A special study focused on high temporal resolution DO data over a tidal cycle in Cobscook Bay would provide additional evidence for this claim. Extending the time period from a tidal cycle to a few months, August to October for instance, would aid in addressing the seasonal DO minima question. If these studies could be conducted both in the vicinity of an active aquaculture facility and at reference sites it would benefit both the regulators and industry. This type of study could be used to evaluate proposed changes to FAMP and the validity of these changes and the program overall.

A potential resource for conducting time series DO measurements in Cobscook Bay is the Gulf of Maine Ocean Observing System (GoMOOS). They currently have a mooring in the bay and have been including DO sensors on buoy instrument arrays in other areas (e.g., Massachusetts and Casco Bays). The availability of DO time series data would be advantageous for FAMP on many different levels – interpretation of data, potentially a long-term reference site (depending on location), and a tool for evaluating the FAMP sampling schedule.

4.2.3 Water Quality Standards, Parameters, and Models

As this evaluation has progressed, a number of ancillary issues have been discussed in the context of providing additional information on the impact aquaculture facilities might have on local and regional water quality conditions. These topics are presented briefly to simply acknowledge the issues and provide a basis for further discussion.

Currently, the MDEP general permit is expected to focus on DO concentration rather than percent saturation. The ecological importance of the DO concentration has been discussed by Heinig (2000a) as it pertains to the FAMP. EPA has focused on DO concentration with the establishment of a 4.8 mg/L water quality criteria for waters from Cape Cod to Cape Hatteras (US EPA 2000). The relative importance of concentration versus percent saturation is beyond the scope of this evaluation. It should be noted that regardless of the outcome of the debate, the FAMP will measure and assess whatever the final permit or statute states.

The EPA site-specific permit for the proposed Acadia facility (defunct) defined both DO concentration and % saturation standards (6 mg/L and 85%) and required the collection of samples for a suite of nutrient, chlorophyll and phytoplankton measurements in the 'farfield.' Although these requirements would have to be met by the site operator and not necessarily FAMP, it may serve MDMR to conduct a special study in Cobscook, Machias, or Blue Hill Bay to understand the nutrient and organic loadings from aquaculture facilities and feed into some estimates of assimilative capacity of the embayments and modeling approaches.

This type of data would lend to a better assessment of the impact of aquaculture on a regional level, which is not addressed directly by FAMP as currently designed. In addition to any impact that might be related to inputs of dissolved inorganic nutrients, there is the potential for regional effects on dissolved oxygen due to elevated BOD and SOD on the ecosystems of the bays and estuaries where the aquaculture facilities are located. As it currently stands, FAMP is essentially measuring the impact of respiration and not directly evaluating the impact of BOD/SOD. It has been estimated that SOD is ~1/2 respiration and that respiration is 100-200 g O_2/hr/ton of fish (Silvert 1994). The 'impact' of respiration increases as the biomass increases and ambient levels decrease – so in the fall prior to harvesting, respiration would be expected to have the greatest 'impact.' BOD and SOD, however, are directly tied to temperature and its effect on biological rates in the water column and sediments and would likely have more of an impact on DO levels in July to September. The SOD is most likely to impact bottom water in the vicinity of the pens and though this is not directly measured, an indirect assessment is made by the evaluation of RPD and benthic community. A more quantitative assessment would be useful. In contrast, BOD has a more diffuse and regional impact as the organic material will be degraded on a timescale of days rather than hours and travel beyond the immediate vicinity of the aquaculture facility. Measurements of both SOD and BOD would need to be made to better characterize these impacts.

The data on nutrients, chlorophyll, and SOD/BOD would also be useful for development of models with which to better understand the assimilative capacity of the embayments and the regional impacts of finfish aquaculture. Models could not take the place of monitoring as far as assessing compliance with water quality standards, but they would be a useful management tool for understanding the impacts of aquaculture on both local and regional water quality (and benthos). A comprehensive assessment of the assimilative capacity of an embayment would also entail quantifying the impact of other point and non-point sources to the system (i.e., industrial facilities, agriculture, wastewater treatment plants, etc.). Although management of these inputs does not fall under the purview of MDMR, their effects must be understood in order to gauge the relative impact of aquaculture activities on the embayment. It may be possible to undertake an assessment of the assimilative capacity of an embayment in coordination with other regulatory agencies (MDEP, EPA) and stakeholder groups to defray the costs of such a comprehensive study. Currently, the FAMP is designed as a compliance monitoring program, but if future permits are as comprehensive as the site-specific permit EPA proposed for Acadia Aquaculture Inc., FAMP may be redesigned to provide data with which to assess compliance and to be used in the development and validation of applicable models.

4.3 BENTHOS

4.3.1 Experimental Design

To assess whether there is a significant change in the benthic community, it is essential that a monitoring program be designed to answer specific questions. Green (1979) lists the following principles:

1. Be able to state concisely what question you are asking.
2. Take replicate samples within each combination of time, location, and any other variable.
3. Take an equal number of randomly allocated replicate samples.
4. Collect samples both where the condition is present and where it is absent.
5. Carry out preliminary sampling to provide a basis for evaluation of design and analysis.
6. Verify that you are sampling the population you think you are sampling.
7. If the area has large-scale environmental patterns, break the area up into relatively homogenous subareas and allocate sampling proportionally to the size of the area.

Quantitative comparison to detect impact relies upon sampling design and appropriate statistical analysis to be effective. The Before-After-Control-Impact sampling design (Green 1979, Stewart-Oaten et al. 1986, GESAMP 1996) is currently the best available method for evaluating whether a significant impact has occurred. Samples are collected both before and after a potential impact and in both control and impact areas. The BACI model lends itself to Analysis of Variance (ANOVA) as well as to various multivariate analyses (numerical classification; multidimensional scaling, etc.). If samples are collected both before and after, and control and impacted areas, ANOVA indicates potential impacts by the significance of the interaction term of time (Before-After) and location (Control-Impact). In the case of FAMP, the BACI design would require establishment of a suitable reference station where comparable baseline data can be collected. In the absence of comparable baseline data, the Control X Impact design, with suitable reference site, should be sufficient.

Selection of an appropriate reference site is fraught with difficulties. First, given the complex bathymetry and hydrodynamics, it is difficult to find comparable sites. Second, many areas, especially in Cobscook Bay, have already been impacted by activities such as trawling (Heinig 2000a). Analyses such as trend analysis, a nonparametric regression (Gilbert 1987) can be used to look for parallel trends when two areas are not directly comparable.

4.3.2 Tiered Sampling

One of the fundamentals of monitoring programs according to GESAMP (1996) is that "the list of monitoring variables should be scaled according to the level of ecological concern." The FAMP monitoring program could be constructed in a tiered fashion. Tier 1 sampling would occur at least annually at all farms adjacent to or underneath the pens as well as at the edge of the mixing zone. It should include a set of relatively inexpensive, rapidly implemented parameters that would allow an assessment of whether there was a risk of benthic impairment. Tier 1 benthic sampling might include video monitoring, sediment sulfide or other surrogate (discussed in further detail below). Impairment could be indicated by existing FAMP standards, using the presence of indicators such as *Beggiatoa*, food deposition, absence of fauna, and gas formation. GESAMP (1996) ranked redox potential (Eh) as a highly valuable benthic parameters and ranked as moderate value, total organic carbon (TOC), total Kjeldahl nitrogen and total nitrogen, and presence of *Beggiatoa*. Suggestion of impairment within a predefined area would trigger improved management practices, at a minimum, and more intensive monitoring.

Tier 2 sampling would focus on quantitatively assessing impairment relative to a suitable reference site. Analyses in addition to the Tier 1 parameters would include randomly collected replicate benthic samples (a minimum of three), discussed more fully below.

One unanswered question is whether Tier 1 sampling should be sufficient to detect benthic impairment. Both the State of Washington and the provinces of New Brunswick and British Columbia use chemical sediment parameters as screening tools. No benthic infauna collections are made unless the chemical sediment parameter thresholds (TOC for Washington, TVS for BC) are exceeded. New Brunswick relies exclusively on video and sediment monitoring with no further biological assessment. Further investigation of the success of these various methods along with a test of its applicability in the State of Maine is recommended (See Section 4.4 Recommendations).

4.3.3 Numeric Benthic Standards vs. Best Professional Judgment

There are strong reasons for developing numeric standards for NPDES permit requirements. First, they ensure consistent, predictable regulatory review, and second, they are in line with other NPDES requirements for freshwater facilities. However, presently, there are no numeric marine biological standards that have been developed for Maine, much less New England. However, there is concern that a "one size fits all" approach to marine facilities with widely varying currents, geology, sedimentary regimes, biological communities, and human impacts will not provide a reliable assessment of impairment.

According to the GESAMP (1996), there are two approaches to monitoring for benthic impacts from aquaculture. One would be to establish standards for metrics, based on research, to define environmental quality objectives. According to GESAMP, current research cannot yet support numeric standards, necessitating reliance on relative standards i.e. proportional changes in metrics compared to a reference site. The advantage of a relative standard, according to GESAMP, is that it in effect creates a farm-specific standard.

There is an initiative to develop numeric standards for the aquaculture program, exemplified in Maine's Draft General Permit (listed in Table 4-1), which parallel those listed in the NPDES permit for Acadia Aquaculture Inc.'s Dunham's Cove facility.

TABLE 4-1. SEDIMENT MIXING ZONE IMPACT THRESHOLDS BETWEEN 5M AND 30M OF NET PEN(S)

Metric	Warning Level	Impact Limit
Redox Potential	Mean value –100 to 100 mV nhe	Mean value <-100 mV nhe
Gas Formation	Presence of anoxic sediments	Compelling evidence
Beggiatoa Coverage	Patchy	$\geq$ 50% photo coverage
Anoxic Sediments	Patchy	$\geq$ 50% photo coverage
Pollution-Tolerant Taxa	Number of individuals in single taxa > 70%	Report information
And	AND	
Pollution-Sensitive Taxa	>50% reduction in mean abundance of taxa not identified as pollution-tolerant	Report information
Taxa richness	>25% reduction in total number of all taxa compared to mean reference site	Report information

We recommend for the short term to continue to utilize the best professional judgement criterion, augmented by quantitative analyses to support conclusions. A parallel assessment using working numeric standards should be undertaken to evaluate the long-term utility of numeric standards in the evaluation of impairment.

4.3.4 Video Monitoring

Video monitoring is an important component of the FAMP. However, the goals of the video program should be clarified to maximize effectiveness. If the goal is basically an "early warning system" to detect degraded or degrading conditions within the site, then video (or photographic, if depths preclude the use of diver-operated video) monitoring could be streamlined to look at only these conditions. As currently done, all sites should be monitored at least annually during the fall when conditions are most likely 'worst case", with increased frequency if impairment is indicated.

If video monitoring is to be part of a Before-After-Control-Impact study design, then adjustments should be made to make it a more quantitative estimate, and include appropriate reference stations. Modifications could include estimates of abundance or percent cover for an established number of quadrats (area based on visibility or pre-established width or frames of the video recording) within each substrate or benthic community type along the transect. A set list of metrics (including specific species) to be included in the video review would ensure consistency.

The current method of graphic presentation allows the user to rapidly scan the results; however, when the community is dense, results are difficult to interpret. Tabular presentation of quantitative results would enable a more consistent comparison between time periods; these results could be analyzed statistically as necessary. The province of British Columbia currently includes both quantitative and qualitative elements (BC Ministry of Water, Land and Air, 2002). The New Brunswick Canada video monitoring protocol establishes a survey width of 2 m for 10 m increments of the 50 m transect. Observations include semi-quantitative ranking of indicators such as gas bubble production, presence of feed, presence of feces, and macrofauna abundance; as well as measurements of sediment thickness, and percent *Beggiatoa* coverage (New Brunswick Dept. of the Environment and Local Government 2001).

As pens begin to be installed in deeper waters, provisions for remote sampling (e.g., without divers) should be included. For example, still photography (at a frequency to be consistent with video monitoring) or remotely operated video could allow non-diver sampling. Results must be made consistent among differing sampling methods. The REMOTS™ sediment-profile camera (Rhoads and Germano 1982) is an alternative to video photography. This instrument is an optical prism that operates like an inverted periscope that is vertically inserted in the benthos, viewing the sediment (and associated benthic community) in profile. REMOTS, has the advantage of being able to view subsurface conditions, including infauna, discontinuity layers, rapidly and in real time. Both biological (epifauna, infauna, feeding voids, successional state, tube types and density) and physical-chemical (grain size, sediment surface relief, redox layer characteristics, methane gas vesicles) parameters can be recorded, allowing the scientist to estimate the successional stage of the benthos. Its best use is for reconnaissance level mapping, which can be supplemented with traditional benthic infaunal analysis in targeted areas.

4.3.5 Sediment Parameters

Other sediment parameters could augment the benthic assessment. Sediment grain size is helpful to explain changes in benthic communities. Of course, salmon culture may alter sediment grain size, and indirectly affect the benthos. In Eastern Canada, Hargrave et al. (1994) found that organic carbon, sediment sulfides, and redox potential were effective in identifying adverse benthic impacts from salmon culture. Brooks (2001) found that both sediment sulfides and redox potential were highly correlated with number of benthic taxa. He suggests that benthic fauna respond to three sulfide regimes. In contrast, the State of Washington relies on total organic carbon (TOC) “triggers” to screen sediments for potential impairment (WAC 173-204). The triggers vary depending on percent silt clay in the sediment. Exceedances require benthic infauna analysis. The province of British Columbia is relying upon total volatile solids (TVS) rather than TOC, collecting sediment at a 100 m “outer sediment impact zone.” TVS levels are not allowed to exceed the upper 90th percentile of either a local reference station or, if there is no suitable reference station, baseline levels. The Province of New Brunswick, following Wildish’s work, defines oxidation state of sediments using redox and sulfide. Thresholds for both, not either, parameters define the oxic level:

- Oxic 1: Redox ≥100 mV; Sulfide ≤ 300 µM
- Oxic 2: Redox 0 to100 mV; Sulfide 300- 1300 µM
- Hypoxic: Redox 0 to -100 mV; Sulfide 1300- 6000 µM
- Anoxic: Redox ≤-100 mV; Sulfide ≥6000 µM

Hypoxic and anoxic conditions trigger remedial measures.

Sediment parameters could be an essential component of Tiered sampling. Therefore, we recommend a special study to select from a full range of sediment parameters (TOC, TVS, Redox, grain size) to determine those that are the most appropriate for use in benthic monitoring. The potential for the use of sediment surrogates to replace infaunal analysis in the long term can be considered once Tiered sampling has been implemented, but should not be considered in the short term.

Issues have been raised with respect to the potential for increased concentrations of heavy metals and organics in sediments, resulting from contaminants in salmon feed. Given results from studies conducted in nearby New Brunswick, it does not make sense to make this a routine monitoring component before investigating the presence of contaminants in sediments around salmon pens. We recommend a special study that evaluates the presence of contaminants (metals, PAHs, PCBs, pesticides) at all farms with fine grained sediments. Samples should be collected adjacent to active net pens, with additional samples collected at suitable reference areas, archived for later analysis if net pen samples indicate presence of any of the listed constituents.

4.3.6 Benthic Metrics

The current FAMP relies upon a professional judgement of benthic metrics including percent Capitellidae, taxa richness, and species diversity. These metrics are reliable and supported the scientific literature (e.g., Weisberg et al. 1997). H' species diversity has the advantage of being independent of sample size or total abundance. Other programs have been using indices related to the relative abundance of pollution-tolerant species or opportunistic species, or conversely presence of deep-dwelling Stage 3 species (Table 4-1), indices which have been successfully used in the Chesapeake (Weisberg et al. 1997). All of these metrics should be evaluated in a special study to select those that are most representative. If pollution-tolerant or pollution-sensitive species are to be used in metrics, a task force of benthic ecologists should develop a working list of pollution-tolerant and pollution-sensitive species for the State, separated according to salinity and substrate type.

We recommend the use of a BACI design, with baseline data and a reference station rather than numeric standard for these metrics, as is used in both Washington State and the province of British Columbia (Table 4-2). This would require collecting random replicate samples within the mixing zone and at a reference station. Additional thought needs to be given to the statistical design, acceptable probability levels, and exact metrics to be used. Number of taxa or number of taxa within major taxonomic group (annelid, crustacean, mollusc) is generally a reliable indicator, whereas abundance is generally not. Once a metric is selected, a power analysis could confirm the necessary number of samples to determine, for example, a 50% change in number of species with 90% confidence.

TABLE 4-2. COMPARISON OF BENTHIC COMMUNITY METRICS USED TO EVALUATE IMPAIRMENT

Metric	Washington State	British Columbia
Abundance	50% decrease in abundance of polychaetes, mollusc, or crustaceans compared to reference.	Significant decrease in abundance or percent cover of polychaetes, mollusc, or crustaceans compared to reference.
Taxa Richness	None	Significant decrease in species richness of polychaetes, mollusc, or crustaceans compared to reference.

Use of taxa richness as a measure of impairment assumes that the sample processing protocol (including sieve size, level of taxonomic identification) is consistent throughout the program. We recommend continued use of the 1.0 mm sieve size and lowest practical taxon (species level) identification. An evaluation of how use of family-level or class level identification affects conclusions could be performed if there is interest in reducing sample processing time. In British Columbia, family level is used in soft bottoms and class level in hard substrates. Ammann et al. (1997) found phyla level identification to be sufficient to determine adverse impacts in the majority of studies.

As pens begin to be installed in deeper waters, provisions for remote sampling (e.g., without divers) should be considered, such as use of a grab. Results must be made consistent among sampling methods (rarefaction method for taxa richness, abundance per square meter, as presented in Heinig 2000a).

4.3.7 Sampling Locations

Aquaculture net pens are occasionally moved within lease sites as the lease operator refines husbandry to take best advantage of water currents, protects the pens from storms and respects local landowner seasonal wishes regarding viewscapes. Pen sizes, numbers, configurations, shapes and types also change over time as the technology advances. Not surprisingly, this presents an enormous challenge to long term monitoring. A specific location within the lease site may at one time be underneath the net pen and later be beyond the 30 m distance. Furthermore, unlike in rivers where flow is unidirectional, ocean currents are extremely variable, changing with season, tide, and depth. Thus a “sediment impact zone” is not easily or predictably defined on the lease site. It is essential, however, that coordinates for pen locations and sampling locations be collected during each event so that at a minimum, samples can be interpreted in relation to their location relative to the pens and pen history.

One option would be to create one large area or polygon that surrounds all of the active pens, creating a zone for monitoring conditions under the pens. A second area at a set distance (perhaps 5 m) around the polygon could form the mixing zone, with a third concentric area (perhaps 30 meters from the original zone) created to form the nearfield zone.

4.3.8 Other Considerations

Data Management

As discussed in Section 4.2.1, the FAMP would benefit from the development of a database. This would minimize difficulties in analyzing multiple years of data. The database should be developed in easily utilized standard software. Consideration should be given to developing linkage with Geographic Information Systems. One of the advantages of a GIS system is that it could incorporate the changing locations of net pens within the lease site and permit better tracking of recovery after pens or fish are removed. At a minimum, stations should be named consistently throughout the program and should have geographic reference points within the database. The MDMR began development of just such a database in 2000 and expects it to be ready for use early in 2003.

Sampling Consistency and Evolution

Any multiple-year monitoring program confronts the issue of using the most up-to- date methods while preserving comparability between new and old technologies and methods. Over the history of the FAMP, equipment has improved (e.g., transition of video from 8 mm to digital) and techniques have changed (e.g., sieve size). While we encourage continuous improvement, it is critical to maintain consistent collection and processing protocol, with appropriate quality assurance and quality control (QC/QA). Changes in protocol should be made only if necessary, with appropriate analyses to ensure data compatibility. Regular, independent audits will help assure data quality. A written protocol (standard operating procedures or SOPs) is important to maintain consistency. The Canadian provinces of New Brunswick and British Columbia both have good QA/QC programs.

Wildlife

Wildlife impacts are considered in the siting process but are not included in the FAMP monitoring. There needs to be consensus among the agencies on whether wildlife monitoring is needed, given that there is no current regulatory requirement for monitoring. Interactions between wildlife and aquaculture facilities are mostly anecdotal. The MDMR is conducting one study on the interaction between seals and finfish aquaculture (Marcy Nelson, University of Maine, personal communication). Special studies could be undertaken in concert with MDIFW (with input from NOAA and USFWS as appropriate) to determine aquaculture effects on wildlife, specifically marine mammals and aquatic birds, with a goal of understanding the risks posed by aquaculture facilities and how they might be minimized. The results of these studies can help to determine the necessity of incorporating a wildlife component into the monitoring program and how it should be designed, or if efforts would be best focused on husbandry practices.

4.4 RECOMMENDATIONS

Our recommendations for water quality and benthic monitoring include the following

1. Define the objectives of water quality protection in terms of the spatial and temporal extent over which standards must be attained.
2. Reevaluate the number and location of reference sites.
3. Examine the use of water quality metrics that are focused on farfield impacts.
4. Institute special studies to better characterize nutrient and organic inputs from aquaculture facilities that provide both an understanding of the current situation and feed into modeling efforts.
5. Examine potential wildlife impacts in a special study designed with input from MDIFW, NOAA and USFWS.
6. Evaluate the presence of contaminants (metals, PAHs, PCBs, pesticides) in all farms with soft substrate.
7. In a small special study, evaluate the presence and associated ecological risk of aquaculture-related pharmaceuticals.
8. Develop a means to determine "carrying capacity" of a water body, using modeling or other techniques.
9. Augment the existing sampling design by including replicates and a reference station in order to utilize the BACI experimental design.
10. Expand video monitoring to include quantitative elements.

11. In a special study, evaluate effectiveness of sediment parameters such as redox potential and sulfide in assessing impairment.
12. Evaluate use of other benthic metrics such as percent pollution-tolerant or percent pollution sensitive species.
13. Institute a tiered sampling protocol, relying on Tier 1 sampling such as sediment sampling and video monitoring to detect potential impairment, and benthic infauna sampling in cases where Tier 1 sampling suggests impairment. Evaluate effectiveness.
14. Evaluate the effectiveness of numeric standards by using draft standards in parallel with professional judgement relying upon statistically verifiable results.

5.0 PROPOSED MONITORING PROGRAM

5.1 PROPOSED SPATIAL DESIGNATIONS

The proposed monitoring program differs from the current FAMP program in two ways. The proposed program includes several concentric spatial zones in the sampling regime. Further, the proposed program uses a system of sequential sampling, with increasing intensity depending on initial sampling results.

The proposed monitoring program would be divided into several spatial zones: the individual net pens (same as the current FAMP program), "inside," "mixing zone," nearfield and reference. Certain elements of the monitoring program would occur around and near the net pens, as occurs currently. A "polygon" would be delineated within the lease site at a distance of 5 m around existing net pens to form a sampling area called "inside zone." A second polygon would be drawn around the inside polygon at a distance of 30 m to form the "mixing zone." The nearfield zone would be defined as a 100-meter polygon drawn around the inside zone, or the edge of the lease site, whichever is closer. A reference station would be selected, similar in current regime and substrate and depth (for benthic monitoring) to the inside area but sufficiently distant to be exempt from net pen influences. Ideally, one reference site could serve several lease areas in one area.

TABLE 5-1. PROPOSED SPATIAL DESIGNATIONS

Zone	Distance	Proposed sampling
Net pen	0	Video,
Inside	5 m distant from polygon drawn around net pens	Video
Mixing zone	30 m from inside zone	Video, DO, sediment parameters, infauna if warranted
Nearfield	100 m or edge of lease site	DO if warranted
Reference	Within 1 to 2 km of lease site	DO if warranted

5.2 WATER QUALITY

For the water quality monitoring program, we propose to collect the suite of in situ data as currently implemented by FAMP. Special studies were recommended in the previous section to examine the distribution and impact of other parameters (nutrients, chlorophyll, BOD, etc.), but the proposed monitoring program focuses on reconfiguring the existing effort. Currently, replicate profiles are collected 100 m upstream, 5 m downstream, and 100 m downstream of each pen or six profiles per pen. At large lease sites with multiple pen arrays, this can result in collection of 25 to 30 hydrographic casts at some lease sites (e.g., ASMI-CI). The information garnered from these numerous casts is often difficult to interpret. As shown in Figure 3-2, the definitions of upstream, downstream and specific distances can get confusing. We propose to focus the monitoring effort in zones defined by concentric polygons that surround the footprint of the current site pen configuration and to use an adaptive sampling strategy. Water quality parameters will be measured at four locations along the edge of the mixing zone (30 m). These locations will be both along and perpendicular to the axis of the predominant tidal currents. If DO concentrations are ≤6.5 mg/L and percent saturation is ≤85% at any of these mixing zone sampling locations, then hydrographic cast will also be conducted at four locations at the edge of the nearfield (100 m). In the case of smaller facilities, this sampling approach will be a very minor change. At the larger facilities, this approach will result in both a lower level of effort in the field and a more useful dataset for management and regulatory enforcement of water quality standards.

Hydrographic casts will be conducted at all reference sites. The location of these sites is still to be determined. The reference site should be far enough away to be out of the area of expected influence of the aquaculture facility, but in a similar hydrographic regime. Calculations of mean tidal flow at a site will be useful in estimating reasonable distances from the lease site. It is expected that due to the strong currents and relatively small embayments that these reference sites will have to be within 1 or 2 km of a lease site. One benefit is that each of these sites should serve as a reference for multiple lease sites.

5.3 BENTHOS

The benthic monitoring program is proposed to comprise several tiers or intensities of monitoring and include sequential sampling. Each tier would address a different set of goals. Tier 1 video sampling would continue to occur adjacent to the net pens with a goal of detecting unacceptable impairment levels adjacent to (within 5 m) the net pen systems that would require immediate remediation. The video monitoring would continue to be conducted from a point 30 m downstream to 30 m upstream to assist in delineation of impairment boundaries. Measures of impairment would include unacceptable percentages of *Beggiatoa* and anoxic sediments, along with the presence of accumulated food and evidence of outgassing. We recommend that video monitoring include data collected from quadrats as well as at a reference station. Sites needing remediation would require spring Tier 1 follow-up if fish were still present.

Tier 1 sampling at the edge of the mixing zone would meet the goal of regulatory compliance of no unreasonable impact to the balanced indigenous community. We propose to test the use of sediment parameters (redox potential, total volatile sulfides, along with grain size and total organic carbon to aid in the interpretation of the sediment parameters) as an indicator of benthic impairment in a special study. Should one or more of these prove to be a reliable indicator, the sediment parameters could be used instead of benthic infauna as the Tier 1 sampling regime. If sediment parameters indicate impairment, Tier 2 sampling could be implemented. This would include a minimum of three benthic samples both upstream and downstream at the outer edge of the mixing zone, with an additional samples at the upstream and downstream edges of the nearfield zone, along with at least three samples at the reference site. These samples could be collected and archived and processed sequentially. If samples collected at the edge of the nearfield zone showed no significant differences in community metrics from the reference site, no additional samples would need to be analyzed.

In the short term, ANOVA comparisons of all quantitative data to the reference site can be used to evaluate impacts. In the long term, these data can assist in the development of numeric standards as appropriate.

TABLE 5-2. PROPOSED BENTHIC MONITORING PROGRAM

Tier	Parameter	Location	Frequency	Change from Existing
Tier 1	Video	From 30m downstream to 30m upstream of each net pen	Minimum 1 per year, late summer. Spring follow-up as necessary.	Include quantitative elements
Tier 1	Sediment parameters Redox, E_h or Sulfide	Edge of mixing zone	1 per year, late summer, .Spring follow-up as necessary.	New program
Tier 2	Benthic infauna	3 replicates upstream, 3 replicates downstream at edge of mixing zone, nearfield and reference	If video or sediment parameters indicate potential for impairment	Collected on an as needed basis, depending on Tier 1 results. Increased replication, with reference station.

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